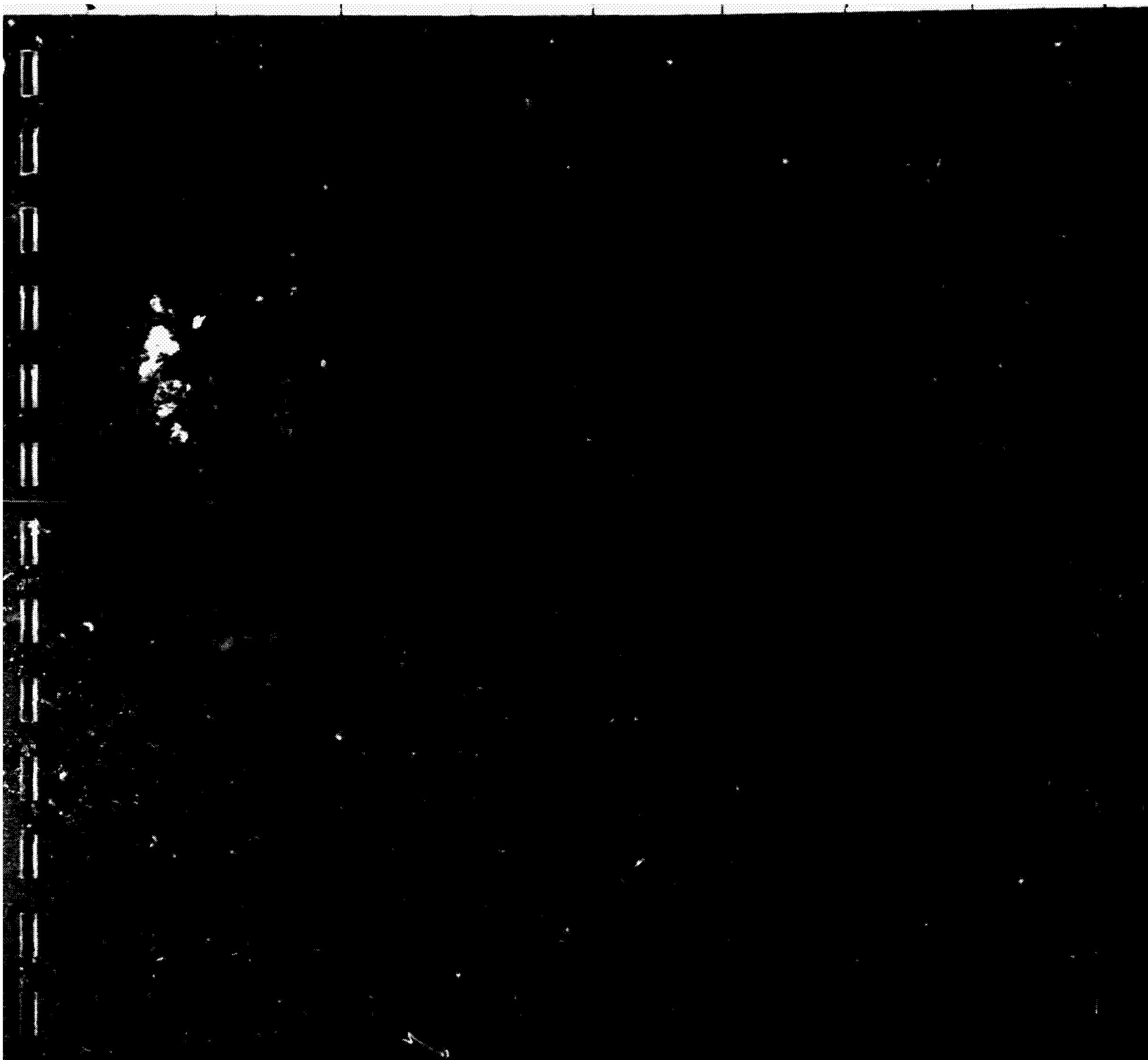

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DPD NO. 524
DR NO. MA-04

MCDONNELL DOUGLAS
CORPORATION

SPACE STATION SYSTEMS ANALYSIS STUDY

PART 2 FINAL REPORT

VOLUME 3
Appendixes
Book 2
Supporting Data
(1 Through 6)

28 FEBRUARY 1977

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CONTRACT NO. NAS 9-14958
DPD NO. 524
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PREFACE

The Space Station Systems Analysis Study is a 15-month effort (April 1976 to June 1977) to identify cost-effective Space Station systems options for a manned space facility capable of orderly growth with regard to both function and orbit location. The study activity has been organized into three parts. Part 1 was a 5-month effort to review candidate objectives, define implementation requirements, and evaluate potential program options in low earth orbit and in geosynchronous orbit. It was completed on 31 August 1976 and was documented in three volumes (Report MDC G6508, dated 1 September 1976).

Part 2 has defined and evaluated specific system options within the framework of the potential program options developed in Part 1. This final report of Part 2 study activity consists of the following:

- Volume 1, Executive Summary
- Volume 2, Technical Report
- Volume 3, Appendixes
  - Book 1, Program Requirements Documentation
  - Book 2, Supporting Data
  - Book 3, Cost and Schedule Data

The third and last portion of the study will be a 5-month effort (February to June 1977) to define a series of program alternatives and refine associated system design concepts so that they satisfy the requirements of the low earth orbit program option in the most cost-effective manner.

During Parts 1 and 2 of the study subcontract support was provided to the McDonnell Douglas Astronautics Company (MDAC) by TRW Systems Group, Aeronutronic Ford Corporation, the Raytheon Company, and Hamilton Standard.

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CONTENTS

Part 1

SCB ORIENTATION CONFIGURATIONS

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Section 1
SCOPE AND CONCLUSIONS

The orientation of the Space Construction Base (SCB) in its many manifestations of configuration is important to both design and logistics resources. The technical areas that are impacted are listed in Table 1-1. Of primary interest for this study were the guidance and control, reaction control, and electrical power subsystems. The amount of impulse required for orbit keeping and attitude control was determined for a variety of orientations of an SCB configuration with both Orbiter and a representative objective element attached. A particular configuration was chosen for analysis of the amount of shadowing of the solar arrays for the electrical power subsystem.

The analysis techniques used were based on digital simulations of the vehicle in orbit. One simulation involved the equations of motion with a complete aerodynamic representation of the vehicle, a dynamic atmosphere, vehicle products and cross products of inertia, and an earth gravity harmonic model. The equations were time-integrated and produced copious outputs associated with orbital geometry, forces, and moments. Another program was used to solve the solar cell shadowing by the vehicle. Various other routines were used in support of the main analysis tasks.

The analysis performed in this study has provided insight into the major variables and has formed the basis for extensions to other configurations. In addition to orientation and configuration, one of the important parameters is the angle between the orbit plane and the sun (defined as β-angle). This angle varies extensively as a function of time, and its extreme values are limited primarily by the orbit inclination.

The broad conclusions are as follows:

- High β-angles are beneficial to both attitude control and solar cell illumination; however, the low β-angles are more prevalent and will drive the designs.

Table 1-1

ATTITUDE ORIENTATION CONSIDERATIONS SUMMARY

- Guidance And Control Subsystem (G&C)
  - Disturbing moments
  - Orbit keeping maneuvers
  - Optical sensors fields of view
- Reaction Control Subsystem (RCS)
  - Attitude control propellant
  - Orbit keeping propellant
  - Thruster location
- Environmental Control And Life Support Subsystem (ECLSS)
  - Heat rejection
  - Radiator shadowing by components of the SCB
- Electrical Power Subsystem (EPS)
  - Solar array orientation relative to the SCB and/or the sun
  - Shadowing of the solar array
- Information Subsystem (ISS)
  - Antennae locations
  - Antennae fields of view
- Objective Element Requirements
  - Pointing during construction
  - Pointing during checkout
  - Acceleration levels
- Experiments
  - Acceleration levels
  - Field of view

- Gravity gradient/centripetal torques predominate over the aerodynamic torques in the 1984-85 time frame. Stabilization of the orbital vehicle so that a principal axis of the moment of inertia ellipsiod (rather than geometric axis) is vertical, is highly desired for minimum impulse.
- The large, aggregate configurations are more demanding of impulse than the simpler ones.
- The orientations with the X-axis (longitudinal) perpendicular to the orbit plane (XPOP) are preferable to others from the standpoint of solar cell shadowing, but not to a greatly significant amount ($\sim$5%). For minimum impulse, there is a slight preference for XPOP, but this difference is overshadowed by the desirability for principle axis stabilization.

The remainder of this appendix addresses the orientation analysis in detail.

Section 2

CONFIGURATION SUMMARY, ORBIT SELECTION, AND ATTITUDE ORIENTATIONS

2.1 CONFIGURATION DEFINITIONS

The configurations chosen for the Space Construction Base (SCB) orientation study are variations of the configuration shown in Figure 2-1. The four configurations considered were:

1. SCB
2. SCB + 30-meter radiometer
3. SCB + Orbiter
4. SCB + 30-meter radiometer + Orbiter

SCB is defined as the fabrication and assembly, space processing, and power and core modules plus the solar arrays. The 30-meter radiometer and Orbiter were attached to the SCB as shown in Figures 2-1 and 2-2. These configurations were selected because they represented possible on-orbit configurations for a construction base that was intermediate in size between the larger 14- or 21-man configuration options and the smaller L' configuration options. The center of mass loaction and principal moment of inertia axes orientation with respect to the vehicle axes (prinicpal axes misalignment) varied considerably between the selected configurations, which allowed the sensitivities to these parameters to be demonstrated. The space processing module was included to generalize the configuration to one which included a radially docked module. The 30-meter radiometer was chosen as a representative objective element that would have significant impact on the SCB mass and aerodynamic properties. Figure 2-2 defines the basic dimensions assumed for the various SCB components.

2.1.1 Mass Properties

The mass properties for each configuration described above are shown in Tables 2-1 through 2-4. Included for each configuration is the mass, center of mass and the components of the inertia dyadic. Forthis study, the

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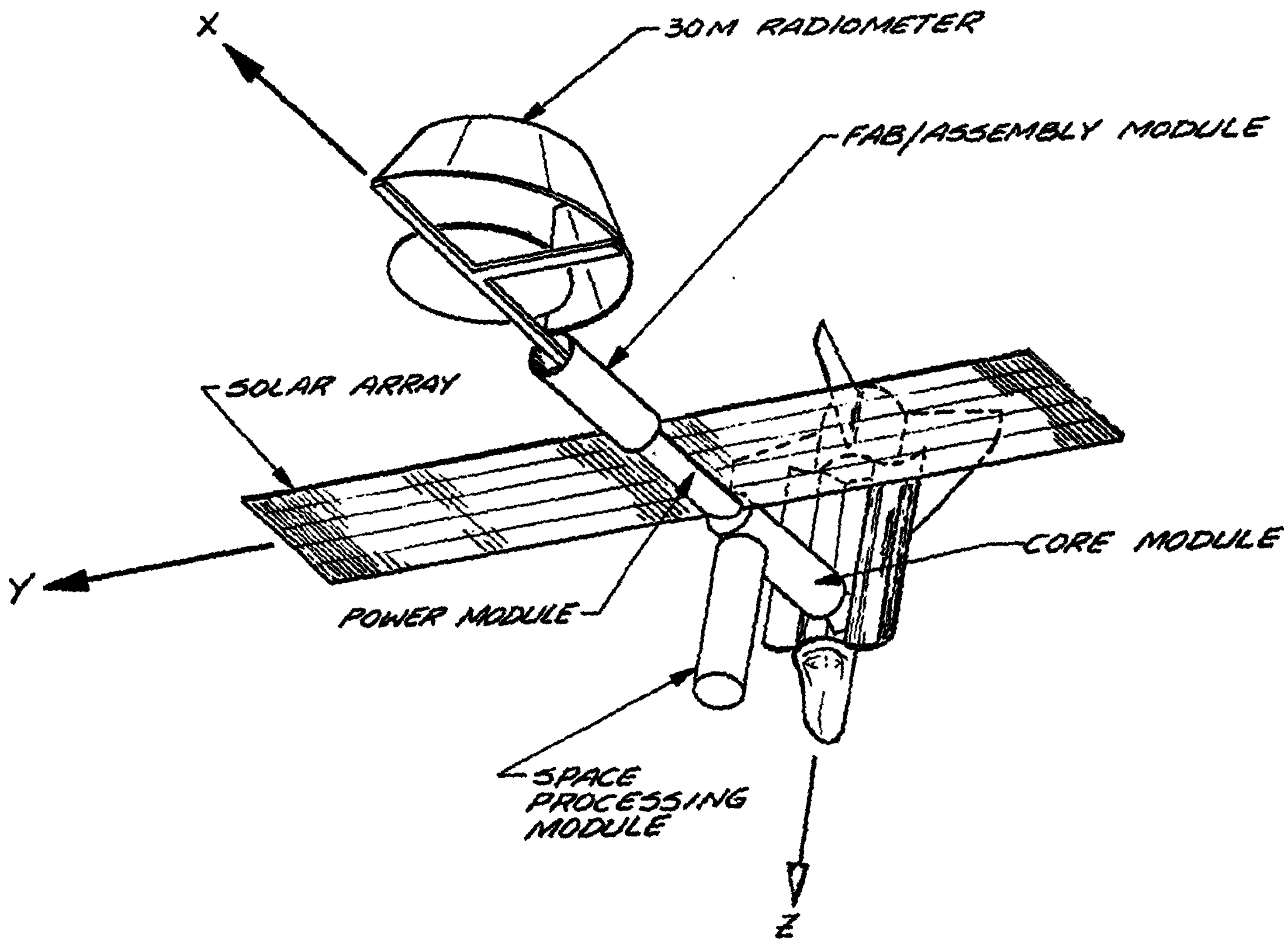


Figure 2-1. Orientation Study Configuration

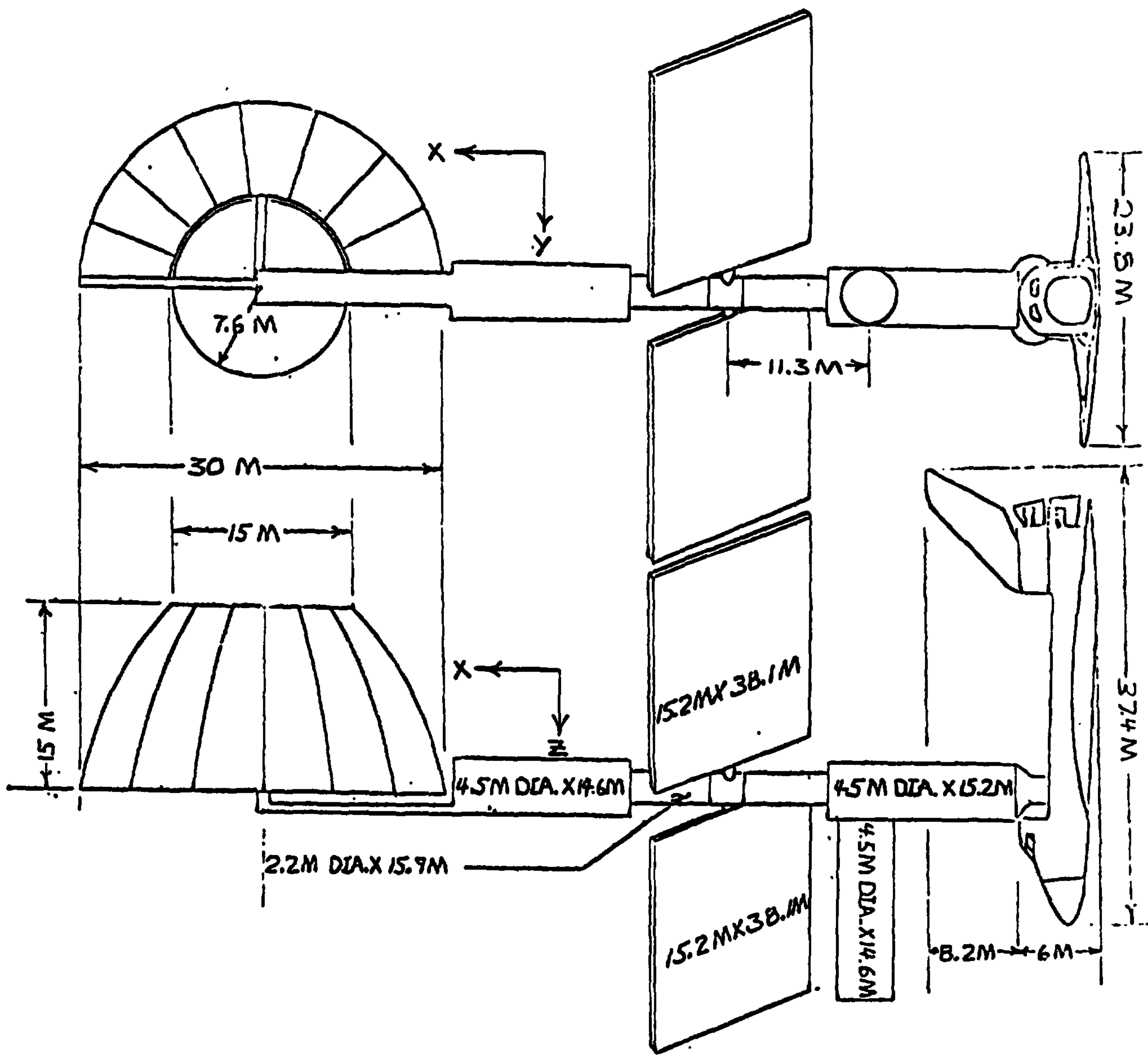


Figure 2-2. SCB Orientation Study Configuration

Table 2-1

MASS PROPERTIES

Configuration: SCB

$$\text{Mass} = 59050 \text{ kg}$$

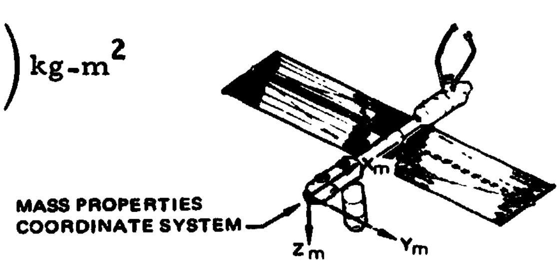
$$\text{Center of Mass} = \begin{pmatrix} 20.52 \\ 0 \\ 2.21 \end{pmatrix} \text{ m}$$

$$\left.\begin{matrix} \text{Inertia Dyadic} \\ \text{(About Center of Mass)} \end{matrix}\right\} = \begin{pmatrix} 3.28 \times 10^6 & 0 & 1.25 \times 10^6 \\ 0 & 1.11 \times 10^7 & 0 \\ 1.25 \times 10^6 & 0 & 1.20 \times 10^6 \end{pmatrix} \text{ kg-m}^2$$

$$(\text{EVEC})^{(1)} = \begin{pmatrix} 0.99025 & 0. & 0.13931 \\ 0. & 1.0000 & 0. \\ -0.13931 & 0. & 0.99025 \end{pmatrix} \quad \text{Unit-Less}$$

$$(\text{ANGLE})^{(2)} = \begin{pmatrix} 8.0081 & 90.000 & 81.992 \\ 90.000 & 0.40711\text{E-}12 & 90.000 \\ 98.008 & 90.000 & 8.0081 \end{pmatrix} \quad \text{Deg}$$

$$\left.\begin{matrix} \text{Principal Moments} \\ \text{of Inertia} \end{matrix}\right\} = \begin{pmatrix} 3.10 \times 10^6 \\ 1.11 \times 10^7 \\ 1.22 \times 10^7 \end{pmatrix} \text{ kg-m}^2$$



(1) Principal inertia axes to body axes direction cosine matrix

(2) $(\text{ANGLE})_{ij} = \cos^{-1}\left[(\text{EVEC})_{ij}\right]$

Table 2-2

MASS PROPERTIES

Configuration: SCB + 30m Radiometer

Mass = 78410 kg

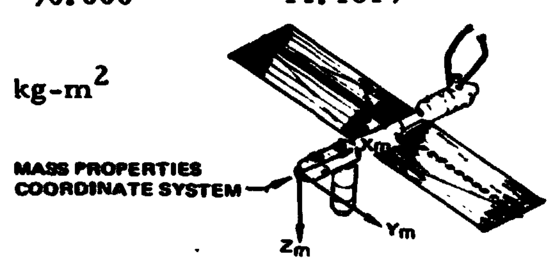
$$\text{Center of Mass} = \begin{pmatrix} 29.21 \\ 0 \\ 0.33 \end{pmatrix} \text{m}$$

$$\left.\begin{array}{r}\text{Inertia Dyadic} \\ \text{(About Center of Mass)}\end{array}\right\} = \begin{pmatrix} 5.82 \times 10^6 & 0 & 5.21 \times 10^6 \\ 0 & 3.18 \times 10^7 & 0 \\ 5.21 \times 10^6 & 0 & 3.11 \times 10^7 \end{pmatrix} \text{kg-m}^2$$

$$(\text{EVEC})^{(1)} = \begin{pmatrix} 0.98102 & 0 \quad 0 & 0.19391 \\ 0 & 1.0 & 0 \\ -0.19391 & 0 & 0.98102 \end{pmatrix} \quad \text{Unit-Less}$$

$$(\text{ANGLE})^{(2)} = \begin{pmatrix} 11.181 & 90.000 & 78.819 \\ 90.000 & 0.40711\text{E-}12 & 90.000 \\ 101.18 & 90.000 & 11.181 \end{pmatrix} \quad \text{Deg}$$

$$\left.\begin{array}{r}\text{Principal Moments} \\ \text{of Inertia}\end{array}\right\} = \begin{pmatrix} 4.79 \times 10^6 \\ 3.18 \times 10^7 \\ 3.22 \times 10^7 \end{pmatrix} \text{kg-m}^2$$



(1) Principal inertia axes to body axes direction cosine matrix

(2) $(\text{ANGLE})_{ij} = \cos^{-1}\left[(\text{EVEC})_{ij}\right]$

Table 2-3
MASS PROPERTIES

Configuration: SCB + Orbiter

$$\text{Mass} = 149950 \text{ kg}$$

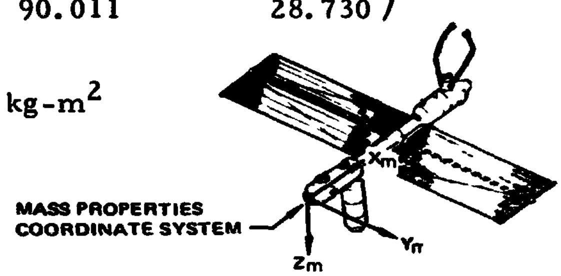
$$\text{Center of Mass} = \begin{pmatrix} 5.64 \\ 0 \\ -6.73 \end{pmatrix} \text{ m}$$

$$\left.\begin{array}{r}\text{Inertia Dyadic} \\ \text{(About Center of Mass)}\end{array}\right\} = \begin{pmatrix} 1.99 \times 10^7 & -8.95 \times 10^3 & -1.17 \times 10^7 \\ -8.95 \times 10^3 & 4.90 \times 10^7 & -5.36 \times 10^3 \\ -1.17 \times 10^7 & -5.36 \times 10^3 & 3.48 \times 10^7 \end{pmatrix} \text{ kg-m}^2$$

$$(\text{EVEC})^{(1)} = \begin{pmatrix} 0.87689 & -0.23250\text{E-}03 & -0.48068 \\ 0.29335\text{E-}03 & 1.0000 & 0.51468\text{E-}04 \\ 0.48068 & -0.18614\text{E-}03 & 0.87689 \end{pmatrix} \text{ Unit-Less}$$

$$(\text{ANGLE})^{(2)} = \begin{pmatrix} 28.730 & 90.013 & 118.73 \\ 89.982 & 0.17065\text{E-}01 & 89.997 \\ 61.270 & 90.011 & 28.730 \end{pmatrix} \text{ Deg}$$

$$\left.\begin{array}{r}\text{Principal Moments} \\ \text{of Inertia}\end{array}\right\} = \begin{pmatrix} 1.34 \times 10^7 \\ 4.90 \times 10^7 \\ 4.12 \times 10^7 \end{pmatrix} \text{ kg-m}^2$$



(1) Principal inertia axes to body axes direction cosine matrix

(2) $(\text{ANGLE})_{ij} = \cos^{-1}\left[(\text{EVEC})_{ij}\right]$

Table 2-4

MASS PROPERTIES

Configuration: SCB + 30m Radiometer

Mass = 169320 kg

Center of Mass

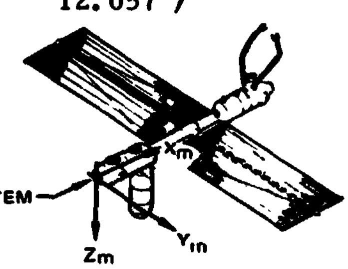
$$\text{Center of Mass} = \begin{pmatrix} 11.35 \\ 0 \\ -6.58 \end{pmatrix} \text{ m}$$

$$\left.\begin{array}{r}\text{Inertia Dyadic} \\ \text{(About Center of Mass)}\end{array}\right\} = \begin{pmatrix} 2.16 \times 10^{7} & -1.43 \times 10^{4} & -1.28 \times 10^{7} \\ -1.43 \times 10^{4} & 9.37 \times 10^{7} & -5.49 \times 10^{3} \\ -1.28 \times 10^{7} & -5.49 \times 10^{3} & 7.87 \times 10^{7} \end{pmatrix} \text{ kg-m}^2$$

$$(\text{EVEC})^{(1)} = \begin{pmatrix} 0.97794 & -0.15673\text{E-}03 & -0.20889 \\ 0.20201\text{E-}03 & 1.0000 & 0.19546\text{E-}03 \\ 0.20889 & -0.23334\text{E-}03 & 0.97794 \end{pmatrix} \text{ Unit Less}$$

$$(\text{ANGLE})^{(2)} = \begin{pmatrix} 12.057 & 90.009 & 102.06 \\ 89.988 & 0.16105\text{E-}01 & 89.989 \\ 77.943 & 90.013 & 12.057 \end{pmatrix} \text{ Deg}$$

$$\left.\begin{array}{r}\text{Principal Moments} \\ \text{of Inertia}\end{array}\right\} = \begin{pmatrix} 1.89 \times 10^{7} \\ 9.37 \times 10^{7} \\ 8.15 \times 10^{7} \end{pmatrix} \text{ kg-m}^2$$



(1) Principal inertia axes to body axes direction cosine matrix

(2) $(\text{ANGLE})_{ij} = \text{COS}^{-1}\left[(\text{EVEC})_{ij}\right]$

inertia dyadic was not updated as a function of solar array position with respect to the SCB. The mass properties correspond to the solar array position shown on the tables. The mass properties coordinate system is shown on each table.

Additional sets of data for each configuration define the principal moments of inertia and the direction of the principal inertia axes (X_p, Y_p, Z_p) with respect to the mass properties axes (X_m, Y_m, Z_m). The "EVEC" matrix is the direction cosine matrix relating the "p" and "m" coordinate frames (P to m transformation matrix). For example, the first column of the EVEC matrix are the components of the X_p unit vector in the m coordinate system. The ANGLE matrix is defined (kj^{th} element);

$$(\text{ANGLE})_{ij} = \text{COS}^{-1}\left[(\text{EVEC})_{ij}\right]. \quad \text{(Degrees)}$$

For example, $(\text{ANGLE})_{12}$ is the angle between the $X_m(1)$ and Y_p (2) axes. For the study configurations, the principal axis misalignment about the X and Z-body axes were negligible. The misalignments about the Y-axis (pitch) ranged from 8 to 29 degrees.

2.1.2 Aerodynamic Coefficient Data

The aerodynamic coefficient data generated included all possible orientations with respect to the orbital velocity vector (see Section 3). The three orientations used for this study (Section 2.2) resulted in the orbital velocity vector lying along the vehicle X axis (XAVV, YPOP, ZDN) and the vehicle ±Y-axis (XPOP, YAVV, ZDN and X_pPOP, Y_pOVV, Z_pDN). The aero coefficients for these conditions are shown in Table 2-5. Moment coefficients are referenced to the center of the solar array gimbal system. The solar array coefficients are treated separately since the solar array moves relative to the rest of the vehicle. The aerodynamic force exerted by the solar array was assumed normal to the array's surface and the solar array normal force coefficient was resolved to the SCB body coordinate system and added to the other aero coefficients. Since the aero reference point was assumed at the solar array gimbal centers, the solar array moment coefficient was always zero.

No aerodynamic shadowing from the relative air stream was included in the aero coefficient calculations. This is evident in the radiometer data for the X-axis along the orbital velocity vector (XAVV). The geometry of Figure 2-1 indicates that the Y-radiometer force coefficient should have a positive value for this orientation. Table 2-5 shows the radiometer Y force coefficient to be zero (Orientation No. 1). This is explained by noting that the radiometer was modeled as a group of elementary surfaces and the forward (+X) portion of the radiometer does not shadow the aft portions from the air stream. Thus, the Y force coefficient of the aft radiometer sections cancel the Y force coefficient of the radiometer forward sections.

Adding all the components of the configurations together without regard to zerodynamic shadowing is conservative from a drag force (force opposite the orbital velocity vector) viewpoint and the orbit keeping requirements for this study can be considered conservative from an aero coefficient viewpoint.

2.2 ORBIT SELECTION

The orbit selected for the orientation study was a 400 km altitude circular orbit with an inclination of 55 degrees. Reference 1 shows that the Shuttle useful payload weight to circular orbit begins to slope sharply downward at 400 km unless an OMS kit is added. Since OMS kits reduce Orbiter payload bay useful volume, they may be undesirable. Preliminary orbit keeping propellant weight calculations indicated 400 km was a viable altitude and was chosen since at that altitude the Shuttle useful payload volume and/or weight was not significantly reduced from the maximum available.

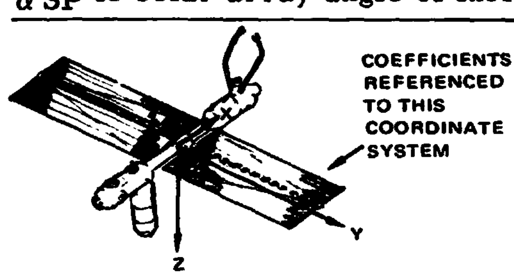
Selection of the 30-meter radiometer as the study configuration objective element led to the 55 degree inclination decision. It was assumed that the desired orbit inclination for the radiometer, once it was operational, would be quite high in order to scan at least the continental USA and a major percentage of the rest of the world. Building the radiometer at the inclination at which it was to operate appeared desirable, and other objective element requirements for initial SCB configurations did not require a lower inclination. The higher inclinations also result in a large range of β-angles (angle between the sun vector and the orbit plane) which was desirable since the solar array

Table 2-5

AERODYNAMIC COEFFICIENT SUMMARY-SCB

Orientation		SCB (No Solar Array)* Force Coef	SCB (No Solar Array)* Moment Coef	30 Meter Radiometer Force Coef	30 Meter Radiometer Moment Coef	Orbiter Force Coef	Orbiter Moment Coef
	X	-6.22	0	-11.78	0	-22.24	0
1 XAVY, YPOP, ZDN	Y	0	-3.28	0	0	0	15.17
	Z	0	0	0	0	-0.82	0
	X	0	3.28	0	0	0	-7.82
2 XPOP, YAVV, ZDN	Y	-19.13	0	-11.78	17.27	-12.95	-0.91
	Z	0	4.18	-7.01	-29.03	-0.51	21.38
	X_p	0	-3.28	0	0	0	7.82
3 X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	Y_p	19.13	0	11.78	-17.27	12.95	-0.91
	Z_p	0	-4.18	7.01	29.03	-0.51	-21.38

*Solar array force COEF $\simeq 75 \sin^2 \alpha_{SP}$ (normal to solar array surface)
α_{SP} is solar array angle of incidence



- Aero reference point at center of solar array gimbals
- Aero reference length = 15.24 m
- Aero reference area = 34.37 m^2

motion relative to the SCB is a function of β, and sun shadowing effects are a function of β. An inclination of 55 degrees was selected as a reasonable high inclination and the associated β-angle range is ±78.5 degrees.

At 400 km altitude, β-angles above about 70.2 degrees result in no sun shadowing by the earth, and the earth shadowing effects range from no shadowing ($\beta > 70.2$ degrees) to 39 percent of the orbit being shaded by the earth (β - 0 degrees) for the orbit chosen. Three β-angles were used for this study: -78.2, 0, and +31.8 degrees. A minus sign means that the vehicle is orbiting clockwise as viewed from the sun, while a positive values denote counterclockwise orbit projections as viewed from the sun. The intermediate value of approximately 32 degrees represents the 50 percent probability condition on β. A derivation of this is found in Section 5.3.2.

2.3 ATTITUDE ORIENTATIONS

Three attitude orientations were used in this study. They are denoted as Orientations No. 1, 2, and 3 throughout this appendix. Table 2-6 defines the orientations relative to the earth and clarifies the nomenclature (XPOP, YOVV, etc.). Earth relative orientation was simulated (GVPAT program, Section 3) by placing the desired vehicle axes along the inertial velocity (AVV and OVV) and current position (DN) vectors. The third vehicle axis was perpendicular to the orbit plane (POP) by definition because of the definition of the orbit plane. Some effects of this orientation definition are discussed in Section 5.1.2. Earth oriented attitudes were assumed because gravity gradient torques were very large, and inertial or sun-oriented attitudes appeared from the start to be undesirable. Orientations No. 1 and 2 were selected to demonstrate aerodynamic drag and moment effects and to show the large gravity gradient/centripetal moments that were possible. Orientation No. 3 was picked to minimize the gravity gradient/centripetal moments.

2.4 SOLAR CELL SHADOWING

An investigation of the amount of shadowing experienced by the solar panels was made to assess the adequacy of their location and possible orientations for one of the configurations. The configuration analyzed is the all-up version shown in Figure 2-1 representing the SCB + 30-meter radiometer + Orbiter.

Table 2-6

SCB ATTITUDE ORIENTATION DEFINITION

Orientation	Definition
1	XAVV, YPOP, ZDN
2	XPOP, YAVV, ZDN
3	X_pPOP, Y_pOVV, Z_pDN

Nomenclature

X, Y, Z	Vehicle Axes as defined in Figure 2-1
X_p, Y_p, Z_p	Principal Inertia Axes
AVV	Along Orbital Inertial Velocity Vector
OVV	Opposite Orbital Inertial Velocity Vector
POP	Perpendicular to the Orbit Plane (Defined to be the plane of the inertial velocity and current position vectors)
DN	Down (toward earth center of mass, not local vertical)

Each solar panel is capable of being rotated about the vehicle X-axis with a second gimbal at a right angles to it to keep it normal to the sun. The Orbiter and radiometer are the primary sources of orbiting vehicle shadowing for each of the panels. Orientations No. 1 and 2 were studied in this analysis for a limited number of β-angles. The time duration that the vehicle is out of the earth's shadow and the amount of unshaded area of the solar panels during this time control their power generating capabilities during each orbit. This study considers both the shadowing effects of the vehicle structure on the solar panels and as well as the effects of the earth's shadow time on their overall performance.

Section 3
SIMULATION OVERVIEW

The primary simulation tool used for the orbit analysis portion of this study was the MDAC General Vehicle Performance Analysis Tool (GVPAT). It is a very general and powerful computer code which performs trajectory computations for many different types of aerospace vehicles. A brief description of the program's various major capabilities is given in the following sections.

3.1 EQUATIONS OF MOTION

Equations of motion for either three or six degrees of freedom are available with the translational equations of motion derivatives being transformed via direction cosines to an earth centered inertial coordinate system for integration. For six DOF the rotational equations of motion are integrated about the vehicle's body coordinate system. For the analysis performed during this phase of the study, three DOF analysis was done for fixed orientations.

3.2 EARTH AND GRAVITY MODEL

The earth model used in GVPAT allows the user to specify a spherical or oblate, rotating or nonrotating earth with up to the fourth earth oblateness harmonic simulated. The oblate earth model used is the one adopted by the ad hoc NASA Standard Constants Committee and documented in report number JPL TR 32-604, dated 6 March 1964.

3.3 ATMOSPHERE MODEL

The atmosphere model used for the SCB analysis is the MDAC 1975 Atmosphere developed for the United States Air Force Office of Scientific Research under contract number F44620-72-C-0084 and is documented in a final report titled "Response of the Magnetosphere and Atmosphere to the Solar Wind" and dated December 1975. It includes the effects due to solar activity (10.7 cm solar flux), time of year, time of day (diurnal bulge), and earth geometric effects on the earth's upper atmosphere. This atmosphere has been compared to and

judged better than the well known Jachia atmosphere model in that MDAC 1975 better matches observed actual satellite data. The analysis performed for this portion of the study was performed for the 1984-1985 time frame for which it is estimated that the 10.7 cm solar flux level will be about at a minimum level (a value of 73 was used). The solar flux level has an eleven year period for its cyclic behavior. The solar maximum activity level should then occur at about the 1990 time frame and should produce a 10.7 cm solar flux level of about 200. Such a variation will increase the earth atmosphere at orbit altitudes by approximately an order of magnitude.

3.4 MASS PROPERTIES

GVPAT can simulate a multiple mass stage vehicle with all three axes simulated for center of gravity and moments and products of inertia. Staging of the mass stages may occur at arbitrary times during the trajectory.

Gravity gradient and centripetal moments are generally lumped together since they result from a common derivation of moment balance on a satellite in orbit. The centripetal moment is sometimes referred to as centripetal force gradient moment or distributed centripetal force moment. It results from the internal force distribution within the rotating body and is an internal moment in contrast to the external gravity gradient and aerodynamic moments.

In general, the six degree-of-freedom equations of motion of a rigid body may be separated into the translational equations of motion of the center of mass and the rotational equations of motion about the center of mass. The GVPAT program was used in a three degree-of-freedom mode for this analysis which meant that only the translational equations of motion were integrated. In order to evaluate the attitude control requirements with respect to disturbing moments, side calculations within the GVPAT program were made and output. The calculations were based on the following discussion.

The rotational equations of motion about the vehicle center of mass are

$$\vec{M}_T = \frac{d}{dt} (\vec{\vec{I}} \cdot \vec{\omega}) + \vec{\omega} \times (\vec{\vec{I}} \cdot \vec{\omega}) \qquad (1)$$

where

M_T = total external moment vector about the center of mass

$\overleftrightarrow{I}$ = inertia dyadic about the center of mass and relative to the rotating coordinate frame

$\vec{\omega}$ = angular rate vector of the rotating body

The time derivative is taken in rotating body coordinator. The total moment is

$$\vec{M}_T = \vec{M}_C + \vec{M}_A + \vec{M}_{GG} \tag{2}$$

where

$\vec{M}_C$ = control moment

$\vec{M}_A$ = aero moment and

$\vec{M}_{GG}$ = gravity gradient moment

Assuming that the vehicle is in a circular earth oriented orbit, the vehicle is controlled to have a constant angular rate vector equal to the orbit angular rate vector and

$$\vec{\omega} = \vec{\Omega} = \text{constant vector} \tag{3}$$

and

$$\frac{d}{dt}\,(\overleftrightarrow{I} \cdot \vec{\omega}) = \vec{0} \tag{4}$$

combining, Eq 1, 2, 3, and 4 gives

$$\vec{M}_C - \vec{\Omega} \times (\overleftrightarrow{I} \cdot \vec{\Omega}) + \vec{M}_A + \vec{M}_{GG} = \vec{0} \tag{5}$$

Defining the disturbing moment ($\vec{M}_d$)

$$\vec{M}_d = (\overleftrightarrow{I} \cdot \vec{\Omega}) \times \vec{\Omega} + \vec{M}_A + \vec{M}_{GG} \tag{6}$$

gives

$$\vec{M}_C + \vec{M}_d = \vec{0} \tag{6}$$

which is the rotational equilibrium equation; the control moment plus the disturbing moment is zero. The first term of $\vec{M}_d$ is the centripetal moment. The gravity gradient moment is defined as

$$\vec{M}_{GG} = \frac{-3M\ (\overleftrightarrow{I} \cdot \vec{r}) \times \vec{r}}{|\vec{r}|^5}$$

where

M = earth's gravitational constant

$\vec{r}$ = the radius vector from the center of the earth to the center of mass of the vehicle

This gravity gradient moment equation assumes a radial gravitational field based on a spherical earth of uniform density.

The solar array motion relative to the SCB results in time varying moment of inertia characteristics for the SCB. These effects were not included in this analysis, but will be accommodated at a later date.

3.5 AERODYNAMICS

The vehicle in its many configurations of growth consists of several components in various arrangements. Although at a nominal orbital altitude (400 km), only relatively small forces such as aerodynamic, magnetic, or radiative pressure act upon it, the accumulated effects can be significant over a long duration in terms of energy requirements. For this purpose, aerodynamic force and moment coefficients for the SCB have been developed, and a computer code has been prepared for their calculation.

At 400 km height, the atmosphere is rarefied, and the appropriateness of available methods were examined by criteria thoroughly discussed in

Reference 2. In accordance with this analysis, using a characteristic flow length, L, of 125 ft (solar panel length) and the mean free path, λ, of 28,650 ft, the Knudsen number is found to be

$$K = \frac{\lambda}{L} = 229$$

The flow is concluded to be free molecular since any value above 10 suffices, and an appropriate theory was used for the derivation of aerodynamic coefficients. For the surfaces used in most spacecraft, the assumption of completely diffuse reflection is a correct one and is used in the present computation.

From kinetic theory of gases, expressions for the normal pressure and shear stress, as given in Reference 2, are

$$p = \frac{1}{2}\rho_\infty U_\infty^2 \times \frac{1}{s^2}\left\{\left[\frac{(2 - fn)}{\sqrt{\pi}}(s \sin\theta) + \frac{fn}{2}\sqrt{\frac{T_b}{T_\infty}}\right] e^{-(s \sin\theta)^2} + \left[(2 - fn)\left(s^2 \sin^2\theta + \frac{1}{2}\right) + \frac{fn}{2}\sqrt{\pi}\sqrt{\frac{T_b}{T_\infty}}\, s \sin\theta\right]\left[1 + \mathrm{erf}(s \sin\theta)\right]\right\}$$

$$\tau = \frac{1}{2}\rho_\infty U_\infty^2 \frac{f_t \cos\theta}{\sqrt{\pi}\, s}\left\{e^{-(s \sin\theta)^2} + \sqrt{\pi}\, s \sin\theta\left[1 + \mathrm{erf}(s \sin\theta)\right]\right\}$$

where

s = speed ratio = $U_\infty/\sqrt{2RT_\infty} = \sqrt{\gamma/2}\, M_\infty$

θ = flow impact angle

T_b/T_∞ = body-to-free-stream temperature ratio

f_n = normal momentum accommodation coefficient = 0.95

f_t = tangential momentum accommodation coefficient = 0.95

For cylindrical bodies, integration about the meridian angle, α, yields the normal and tangential force coefficients

$$C_{n,cyl} = \frac{\ell r}{\frac{1}{2}\rho_\infty U_\infty^2 A_{REF}} \int p \sin\alpha \, d\alpha$$

$$C_{t,cyl} = \frac{\ell r}{\frac{1}{2}\rho_\infty U_\infty^2 A_{REF}} \int \tau \sin\alpha \, d\alpha$$

For flat plates, they are

$$C_{n,plate} = \frac{pA_{plate}}{\frac{1}{2}\rho_\infty U_\infty^2 A_{REF}}$$

$$C_{t,plate} = \frac{\tau A_{plate}}{\frac{1}{2}\rho_\infty U_\infty^2 A_{REF}}$$

With the above basic relations, computer codes for calculating the aerodynamic force and moment coefficients are developed for the vehicle. Two possible configurations, one involving the Orbiter during docking, and the other involving the radiometer have complex geometries. For these studies, approximations were used in representing their surface geometry to facilitate the analysis. Also, the extremely complex and difficult problem of shadowing has been neglected, and the present results generated by the code should be considered as the upper limit in most cases. The computer program for any given attitude of the SCB, in terms of the roll angle and the angle of attack, generates the aerodynamic force and moment coefficients of a chosen configuration. They are expressed in vector components in the body oriented coordinate system.

A variable number of aerodynamic stages may be simulated in GVPAT using either body force and moment coefficients or body force and center of pressure coefficients with respect to an aerodynamic reference point for each of

of the vehicle's three axes. Alternately, lift and drag force coefficients can be used instead of chord and normal force coefficients. The aerodynamic coefficients can be functions of up to five arbitrary variables. Changes in the aerodynamic coefficients and their reference lengths and areas may occur at arbitrary times during the trajectory.

The volume of the aerodynamic data generated by the aerodynamics program proved to be large for hand transfer to GVPAT. Therefore, a special program was written which extracted from the aerodynamics computer code print file (again stored on disk) the appropriate data needed for input to GVPAT. This special program read the aerodynamics code print file and output the data in a form ready for direct input to GVPAT. This approach avoided the error-prone hand manipulation and transfer of such a volume of data from computer program to computer program.

3.6 THRUST

From 1 to 16 gimballed engines of arbitrary body placement, with thrust-weight parameters and nozzle exit area input in variable length tabular form as a function of time, may be simulated. Any two of the engines can be restarted multiple times with thrust buildup and tailoff simulation capability for each burn.

3.7 NUMERICAL TECHNIQUES

GVPAT uses a Runge-Jutta integration technique which has second, fourth, and seventh order integration capability all contained within one algorithm. It includes capability for single step automatic step size selection for all user selected orders of integration. During this study seventh order integration was used wherein the automatic step size selected according to an error criterion was approximately 400 sec of trajectory time.

The program has coupled equations which equate sets of input variables with the same dimensions of specified numerical differences.

A multivariable test procedure is available in the program for determining the times at which specified values of selected variables occur and, at those times, cause changes in trajectory calculations.

3.8 COORDINATE SYSTEMS

Various coordinate systems are available for the calculation of vehicle position, velocity, and body orientation. Included in these is a vernal equinox oriented earth centered inertial right-handed coordinate system which is the primary integration coordinate system used to integrate the SCB position and velocity. The body coordinate system used in GVPAT is situated at a user-desired location on the vehicle with the X-axis positive forward, the Y-axis positive wing right, and the Z-axis positive in a downward direction.

3.9 INITIAL CONDITIONS

Initial position, velocity, and orientation of the vehicle may be input in a variety of ways.

3.10 OUTPUT

Any data computed by the program and stored in the primary program working array, called the D array, may be output for printing or user viewing at interactive terminals. Up to 200 parameters may be printed for any one trajectory time point. The units of any parameter can be arbitrarily changed starting at any print time point. The output files which were produced in the process of performing this orientation analysis were preserved both on microfiche and on magnetic tape should there develop further questions at a later date about the behavior of the trajectories generated during this study.

The following list presents a description of the parameters which were selected to be printed for each time point.

TIME	The trajectory time in seconds from the start of simulation.
XI, YI, ZI	The earth centered inertial (ECI) coordinate system position of the SCB. The XI axis points towards the vernal equinox of date, the ZI axis points out the north celestial pole, and the YI axis lies in the equitorial plane to form a right-hand coordinate system. (ft)
XID, YID, ZID	The velocity components of the vehicle in the ECI coordinate system, i.e., the time rate of change of XI, YI, and ZI respectively. (ft/sec)

XIDD, YIDD, ZIDD	The acceleration components of the SCB in the ECI coordinate system, i.e., the time rate of change of XID, YID, and ZID respectively. (ft/sec**2)
XBDD, YBDD, ZBDD	The acceleration components of the SCB in the body coordinate system. These parameters include all forces acting on the body other than gravity. (ft/sec**2)
CHORD, YNORMF, ZNORMF	The aerodynamic force acting on the body expressed in the aerodynamic coordinate system wherein CHORD is positive along the negative x-body coordinate, YNORMF is positive along the positive y-body coordinate, and ZNORMF is positive along the negative z-body coordinate. These aerodynamic forces are considered to act at the aerodynamic reference point which for this SCB orientation analysis was chosen to be the attach point of the solar panels. (lb)
MXCG, MYCG, MZCG	The total aerodynamic moment acting on the body about the center of gravity. (ft-lb)
MXAR, MYAR, MZAR	The aerodynamic moment on the vehicle about the aerodynamic reference point.
CSUBX, CSUBY, CSUBZ	The total aerodynamic force coefficients used to produce CHORD, YNORMF, and ZNORMF respectively.
CSUBMX, CSUBMY, CSUBMZ	The aerodynamic moment coefficients used to compute MXAR, MYAR, and MZAR respectively.
ALPHAP	The angle between the air relative velocity vector and the X-body coordinate axis. Often referred to as the total angle of attack of the vehicle.
PHIA	The aerodynamic roll angle. It is the angle between the projection of the air relative velocity vector onto the Y-Z plane of the body coordinate system and the Z-axis of the body system. (deg)

ALPHA	The pitch angle of attack of the vehicle. The angle between the X-body coordinate axis and the projection of the air relative velocity vector onto the X-Z plane of the body coordinate system. Positive for the air relative velocity vector projection below the X-axis. (deg)
BETA	The yaw angle of attack. The angle between the X-body axis and the projection of the air relative velocity vector onto the X-Y plane of the body coordinate system. Positive for the air relative velocity vector to the left of the X-axis. (deg)
E	The eccentricity of the orbit of the vehicle. (deg)
INC	The inclination of the orbit. (deg)
OMEP	The argument of perigee. (deg)
RI	The radius vector length, i.e., the distance of the vehicle from the center of the earth. (ft)
VI	The inertial velocity of the vehicle. (ft/sec)
RIA	The radius of apogee. (ft)
RIP	The radius of perigee. (ft)
TAU	The orbit period. (min)
NUTA	The true anomaly of the current position of the vehicle along its orbit. (deg)
ASCN	The right ascension of the ascending node of the orbit plane measured from the ECI X-axis (i.e., measured from the vernal equinox). (deg)
NODREG	The nodal regression rate, i.e., the time rate of change of ASCN.
U	The argument of latitude. The angle measured along plane of the orbit between the ascending node and the current vehicle position. Useful for circular orbits where perigee is not well defined. (deg)
S-LAT, S-LONG	The latitude and longitude of the sun measured with respect to the vernal equinox ECI coordinate system. Note that S-LONG is not an earth relative longitude but is rather an inertial longitude. (deg)

XISUN, YISUN, ZISUN	The components of a unit vector in the vernal equinox ECI coordinate system which points from the center of the earth towards the sun.
XBSUN,YBSUN, ZBSUN	The components of a unit vector in the body coordinate system which points from the vehicle body to the sun.
SPROLL, SPPICH	The roll and pitch Euler angles necessary to rotate through in that sequence in order to make the solar panels perpendicular to the rays of the sun. (deg)
SPPHIA, SPALFA	The aerodynamic roll angle and total angle of attack respectively of the solar panels after they have been made to be perpendicular to the suns rays. See PHIA and ALPHAP for more detail. (deg)
VCF	The total impulsive velocity loss due to atmospheric drag on the vehicle. (ft/sec)
VR	The velocity of the vehicle relative to the local wind. (ft/sec)
XRDB, YRDB, ZRDB	The velocity components of the vehicle relative to the local wind expressed in the body coordinate system (ft/sec)
IX, IY, IZ, IXY, IXZ, IYZ	The moments and products of inertia used for making gyroscopic and gravity gradient torque calculations. (slug-ft**2)
GX, GY, GZ	The gravity gradient torque acting on the vehicle in orbit about the vehicle body coordinate system. (ft-lb)
IAMX, IAMY, IAMZ	The integrals of MXCG, MYCG, and MZCG respectively with respect to time. (ft-lb-sec)
IGGX, IGGY, IGGZ	The integrals of GX, GY, and GZ respectively with respect to time. (ft-lb-sec)
ITMX, ITMY, ITMZ	The integrals of the total moment acting on the vehicle, e.g., ITMX=IAMX+IGGX, etc. (ft-lb-sec)
SUNANG	The angle between the earth-sun vector and the earth-vehicle vector. Ordinarily such an angle would only be in the range of 0 to 180 deg, however, if the vehicle is in earth shadow, this angle is forced to be negative. (deg)

SUNB8A	The sun beta angle, i.e., the angle between the rays of the sun and the plane of the orbit. (deg)
GYROX, GYROY, GYROZ	The gyroscopic moments acting on the vehicle about the body coordinate system.
GIX, GIY, GIZ	The acceleration of gravity acting on the vehicle expressed in ECI coordinate system components. (ft/sec**2)
HGT	The altitude of the vehicle above the local earth. (ft)
RHO	The geodetic latitude of the vehicle. (deg)
UMU	The earth relative longitude of the vehicle measured positive west of the prime meridian. (deg)
UMUI	The inertial longitude of the vehicle measured positive in a counterclockwise sense from the vernal equinox ECI X-axis coordinate. (deg)
PICHA2, ROLLA2	The pitch and roll Euler angle sequence which must be rotated through (in that order) to make the solar panels be perpendicular to the rays of the sun. (deg) These angles were computed for compatability with the solar panel shadowing analysis code, P0333, which could only accept angular rotations in this order.

3.11 TRACKING STATIONS

Up to 12 tracking stations with one antenna each may be simulated. The tracking stations can be arbitrarily located.

3.12 GUIDANCE MODES

A variety of open and closed loop guidance modes are available. The guidance mode logic is modularly written to easily accommodate additional modes. Such a capability is highly desirable since almost every vehicle has its own peculiarities of flight mode. There were essentially three types of flight modes used for the SCB orientation analysis. The first is called XPOP and is achieved by having the SCB X-body axis perpendicular to the plane of the orbit, and in these analyses the Y-body axis was placed along the inertial

velocity vector. The second flight mode is called YPOP and is simply an interchange of X and Y in the above description of XPOP. A minimum gravity gradient orientation was also utilized wherein a specified orientation of the SCB body coordinate system axes with respect to the inertial velocity vector was maintained for the trajectory. In all of the cases studied for the current analysis, the Z (or Z_p) axis was aligned with the local vertical, i.e., the SCB was flown in an earth-oriented flight mode rather than a solar inertial flight mode.

3.13 ORBITAL ELEMENTS

A variety of orbital parameters can be calculated.

Due to the volume of data that was generated during this study, a special program was developed which would read a GVPAT print file stored on computer mass storage (disk) and produce plots of the output GVPAT parameters. These plots were displayed on interactive CRT display terminals from which hardprints could be made directly. Thus, the analysts performing the work for this study could see plotted results virtually immediately after the trajectories for a given set of cases had been completed.

Section 4
SOLAR CELL SHADOWING PROGRAMS

The Orbital Thermal Radiation Analyzer Computer Program (P0333) was used to determine the shadow area of the solar panels due to elements of the orbiting vehicle. The program has various options that allow the user to compute geometric radiation shape factors, gray body factors, and time dependent incident and absorbed solar and earth emitted IR heat fluxes for surfaces in a specified orbit. Surface shapes consisting of flat plates, trapezoids, cylinders, spheres, cones, and paraboloids may be input. The program has an option to generate pictorial plots of the surface data to verify that the various surfaces are oriented properly with respect to one another. The program also generates pictorial plots for specified view angles of the surfaces with respect to the earth and sun for a designated orbit. Figure 4-1 shows a pictorial plot of the configuration studied as presented by the computer graphics capability.

This last option was the method utilized to determine the amount of shadowing experienced by the solar panels. Orbital views of the Space Station, as seen from the sun, were specified for five orbit positions of the vehicle, orbital noon, and positions located 45° and 90° before and after orbital noon. The shadowed area was then computed from the plots by numerical integration.

The determination of the orbit fraction in which the solar cells are not shadowed by the earth was accomplished by a small computer routine. The formulation consists of simple trigonometric functions, and, for circular orbits, the sunlit fraction is a function of only altitude and β-angle. The variation of β-angle as a function of time is a function of the earth-axis tilt, earth position around the sun, and satellite orbit regression rate about the earth's polar axis. Orbit regression is a function of altitude and the gravitational parameter associated with the earth's equatorial bulge. These parameters were also programmed in a small computer routine utilizing simple trigonometric functions in order to provide insight into the variation of β-angle with time.

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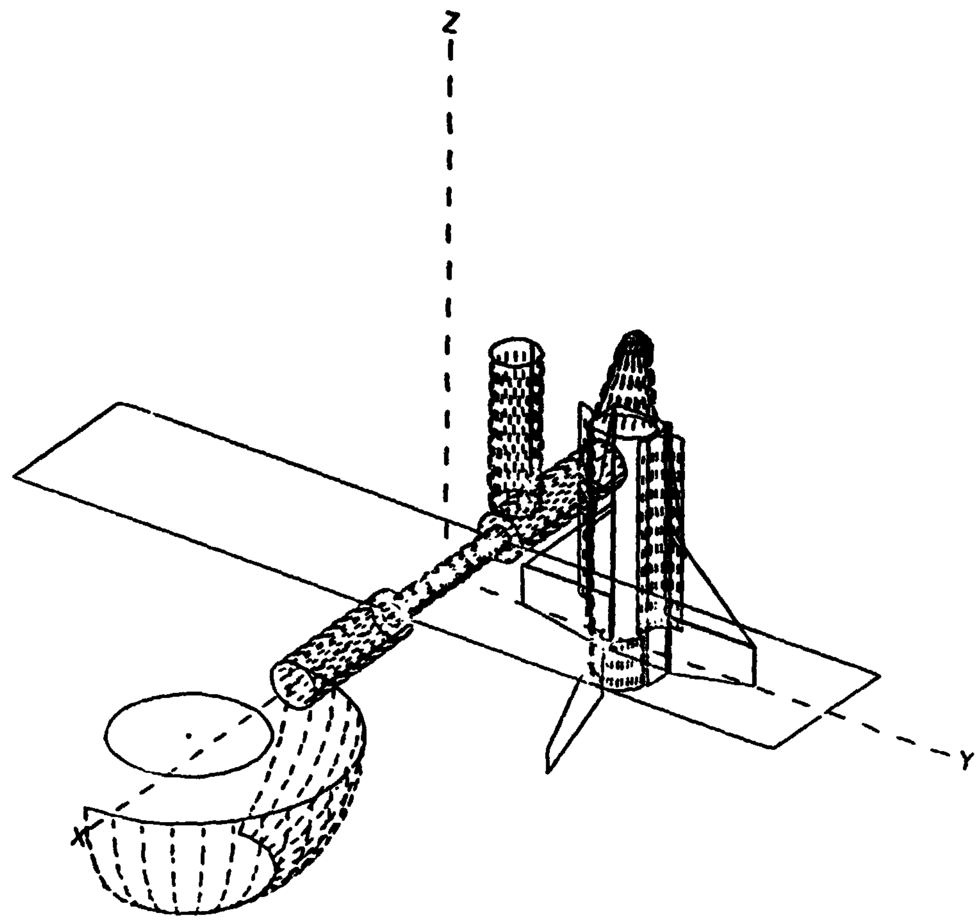

Figure 4-1. Computer Graphics Pictorial Plot

Section 5
SIMULATION RESULTS AND ANALYSIS

The results of this study are divided into RCS impulse and propellant requirements for orbit keeping and disturbing moment control, and shadowing effects on the solar array efficiency. Also included are example plotted outputs of the GVPAT program which illustrate the raw data used to generate the impulse requirements and shows some of the other relevant outputs that were available from the program.

In all, 36 cases were analyzed for impulse and control moment sizing. This represents all possible combinations for the following three parameters:

A. Four configurations (Section 2.1)
B. Three orientations (Table 2-6, Section 2.3)
C. Three β angles (Section 5.3.2)

The average aerodynamic drag force, disturbing moments and RCS impulse and propellant requirements are defined for each case. The solar array shadowing effects are also described for two orientations and two β angles for the maximum configuration (SCB + orbiter + 30-meter radiometer).

5.1 EXAMPLE OF GVPAT OUTPUT FOR DRAG, CONTROL MOMENT, AND IMPULSE SIZING

The case chosen for the example was the following:

A. SCB + orbiter + 30-meter radiometer configuration,
B. XPOP, YAVV, ZDN orientation, and a
C. β-angle of 31.8 deg.

For all 36 cases evaluated, four complete orbits were simulated and plotted out. Section 3.10 has defined the output variables of the GVPAT program. The independent variable for the plotted outputs is either time (sec) or U (deg). U defines the angular position (measured in the orbit plane) of the

vehicle with respect to the line formed by the interaction of the orbit and equatorial planes. U is useful for plotting parameters which are cyclic for each orbit revolution and all four orbits of each case are overlayed on each plot. Figure 5-1 shows U as a function of time. Note that for the circular orbit, U is a linear function of time so that averaging with respect to U is essentially the same as averaging with respect to time.

5.1.1 <u>Geometrical Parameter Outputs</u>

The sun was modeled as orbiting around the earth and this effect for four orbits is shown in Figure 5-2. Over the course of a year, S-LAT has the range of ±23.5 deg (earth's tilt with respect to the ecliptic plane) while S-LONG ranges from 0 to 360 deg. Over the four orbit simulation time, sun motion had insignificant effect on the results.

Figure 5-3 shows a parameter which defines the earth's shadow on the orbit. As discussed in Section 3.10, a negative value of SUNANG indicates the SCB is shadowed by the earth from the sun. For a β angle of 31.8 deg, about

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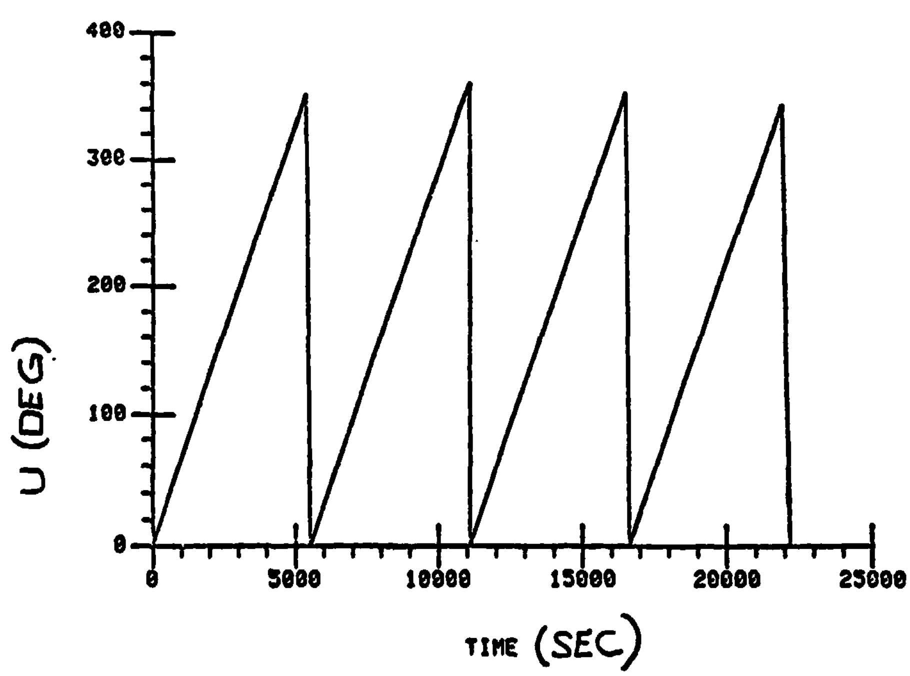

Figure 5-1. Orbital Angular Position History, Example Case

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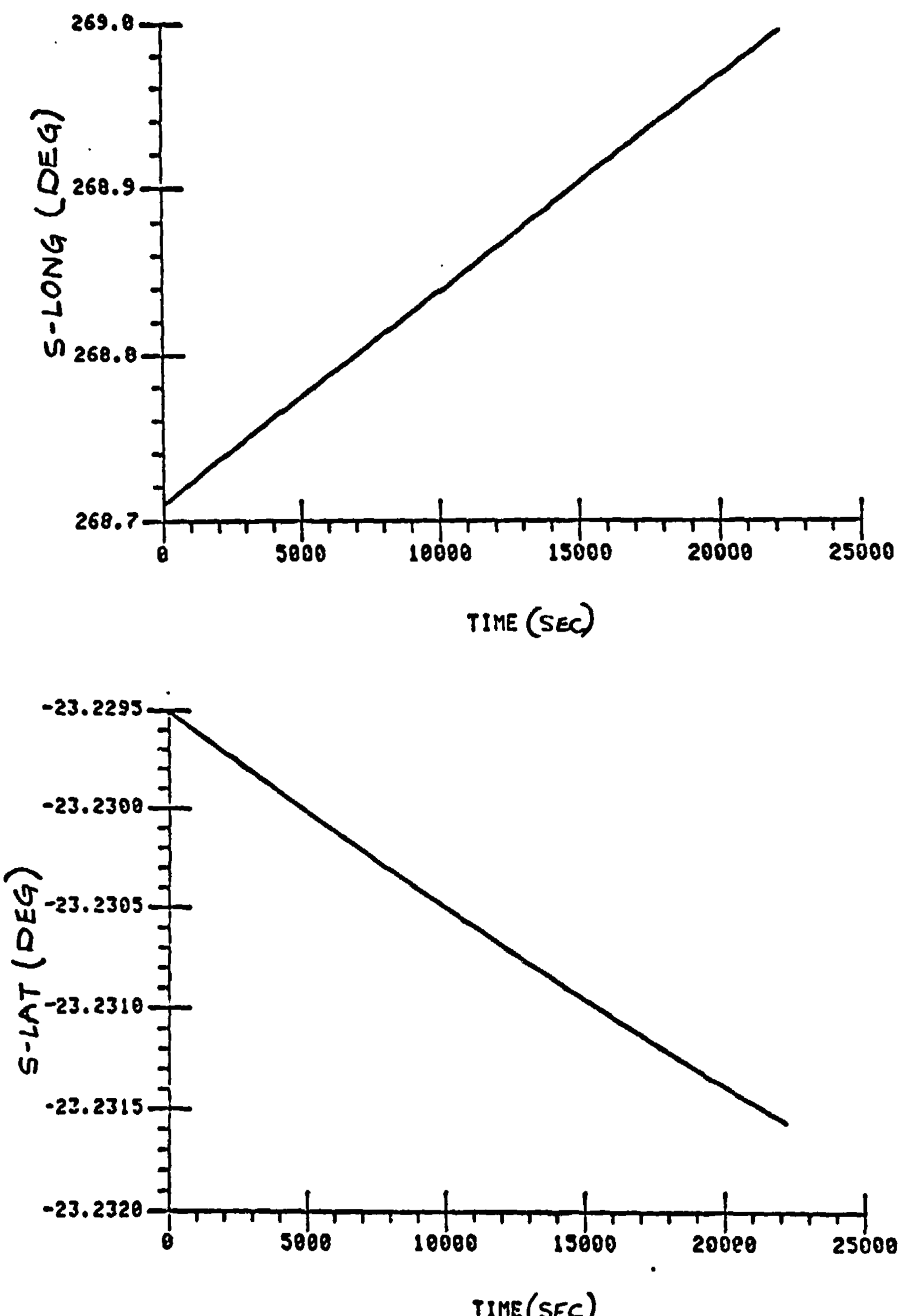

Figure 5-2. Inertial Sun Position History, Example Case

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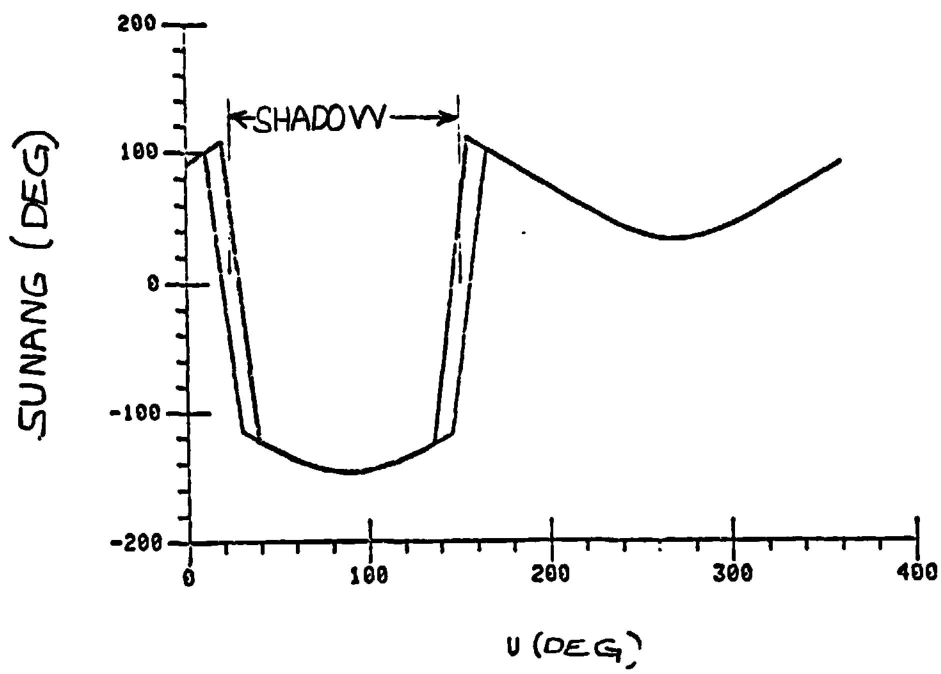

Figure 5-3. Earth's Shadow, Example Case

37 percent of the orbit is in earth shadow. The apparent ambiguity in when the shadow begins and ends is due to a relatively coarse plot interval between successive values of U.

The solar array orientation with respect to the SCB is defined by Figure 5-4. The rotation sequence is roll-pitch. Roll is rotation about the SCB X-axis and pitch about the rotated Y-axis. Direction is defined by the right hand rule and both roll and pitch solar array angles are defined zero when the SCB-to-sun vector is in the minus vehicle Z direction. The roll angle continually decreases while the pitch angle is essentially constant for the XPOP, YAVV, and ZDN orientation used for this example. Note that the pitch angle is the negative of the β-angle for this orientation. The discontinuity in roll angle is not a physical jump in solar array position, but rather a mathematical jump from -180 to +180 degrees in defining the same angle. Again, the apparent ambiguity in the -180 degree crossover point is due to a coarse plot interval.

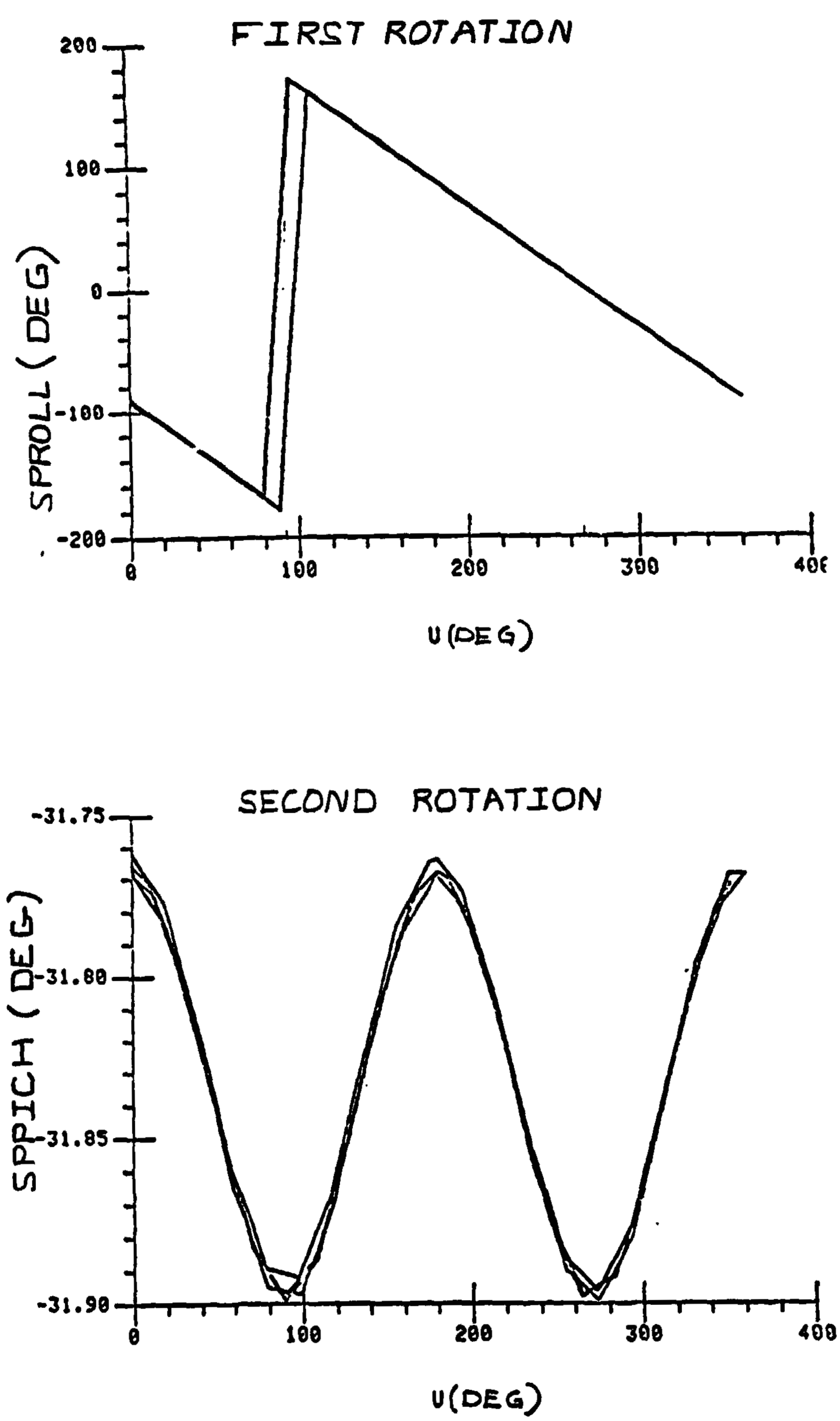

Figure 5-4. Solar Array Position History, Example Case

β-angle is plotted on Figure 5-5. The nominal β-angle for this example case is 31.8 deg but, as Figure 5-5 shows, β is not constant. The variation is primarily due to effects of the oblate earth gravitational model and a long term effect due to the earth's orbital rate about the sun.

5.1.2 Aerodynamic Drag and Disturbing Moment Outputs

Figure 5-6 is a plot of orbital velocity loss (VCF) due to drag as a function of time. This parameter was generated by integrating the vector dot product of the orbital velocity unit vector and the aerodynamic force vector and dividing by the mass. The variability due to the varying solar panel angle to the relative wind is evident. VCF was used to define the average aerodynamic drag force which was used in calculating the orbit-keeping impulse requirement.

The components of the aerodynamic moment vector about the center of mass along with their time integrals are shown in Figure 5-7. The moments vary with the orbit angular positions (U) primarily because the solar panel orientation with respect to the air stream varies and because the air stream varies with respect to the orbit plane as a function of U. The latter effect results when the orbit inclination is not zero. The atmosphere model assumes that the air moved with the surface of the earth and so moved eastward. Orbits with a nonzero inclination have a sinusoidal north-south component which, when a vector summed with the easterly wind speed, results in a sinusoidal angle of attack for an orbit-plane-oriented satellite. Minor effects due to the earth's oblateness also exist.

The YAVV orientation of this example has the solar array parallel to the air stream when the roll solar array gimbal angle (SPROLL) is about zero or ±180 deg. The aerodynamic force due to the solar array is essentially zero for these roll gimbal angles and Figure 5-4 shows the corresponding orbit angular position (U) to be about 90 and 268 degrees. The X and Z aerodynamic moment plots have minimum values at these two values of U and the Y moment reaches a local minimum near 90 degrees. The Y aerodynamic moment has its minimum value near U = 210 deg where the positive moment due to the radiometer is cancelled by the negative Y moment from the solar

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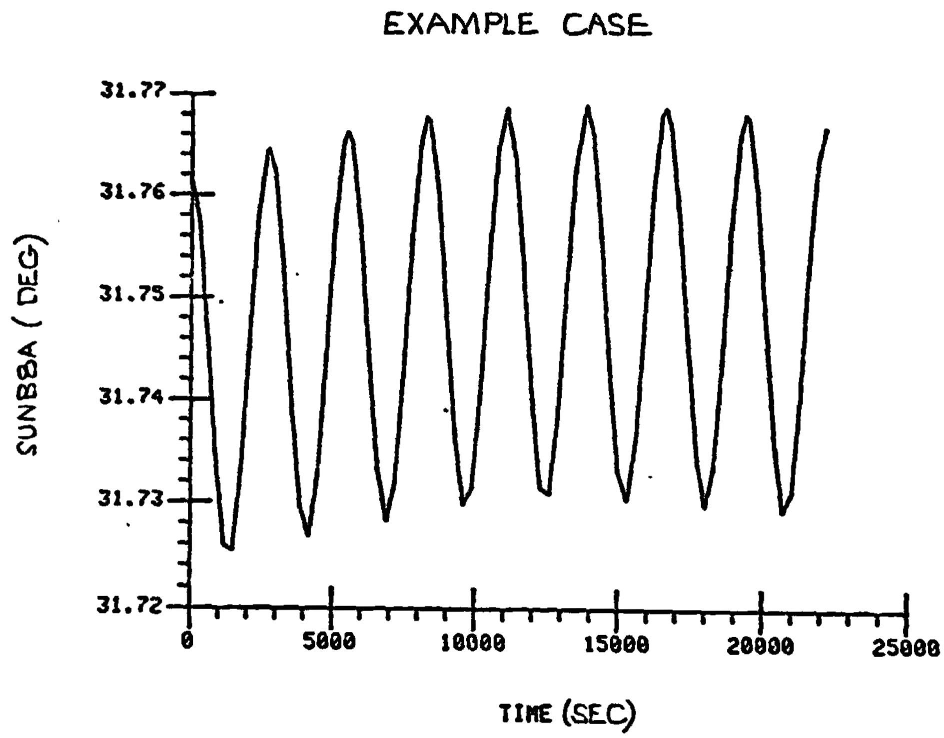

Figure 5-5. B Angle Time History, Example Case

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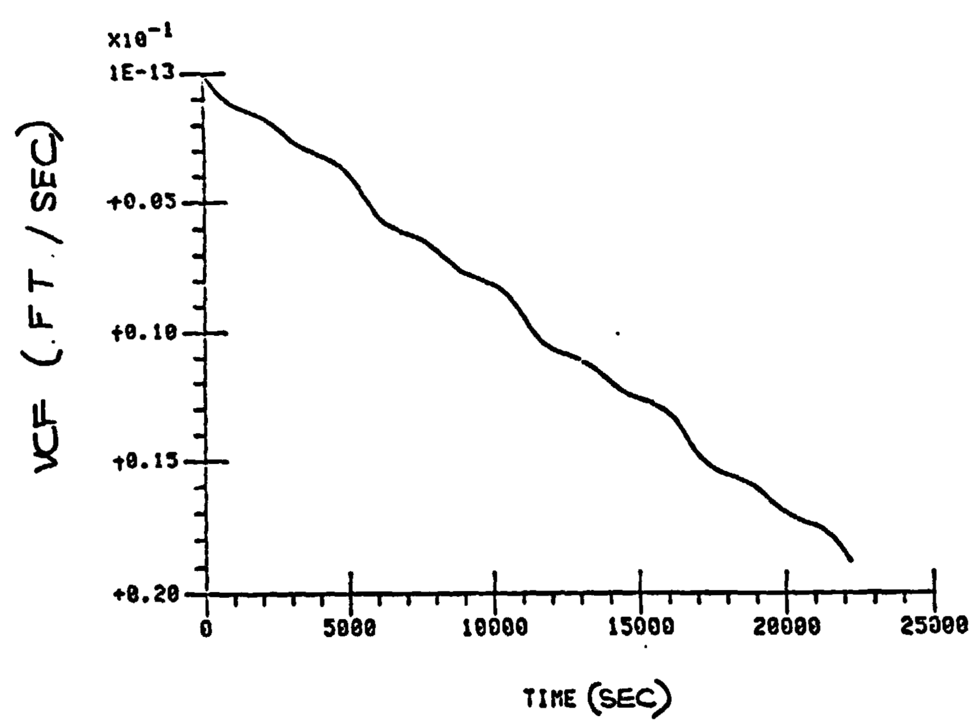

Figure 5-6. Impulsive Velocity Loss Time History, Example Case

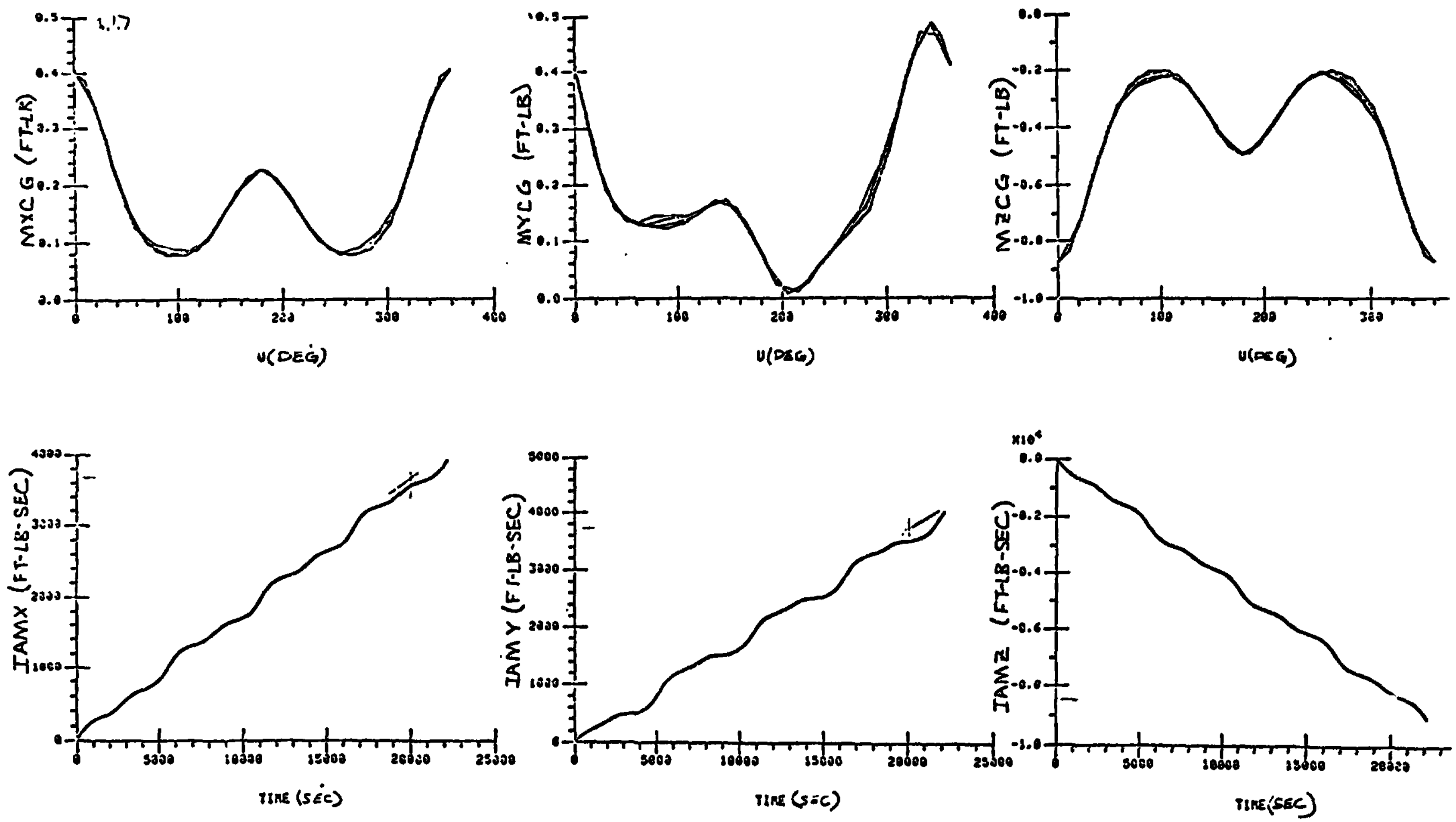

Figure 5-7. Aero-Moment and Moment Impulse Histories, Example Case

array. The aerodynamic moments for SPROLL = 0 are the moments resulting from the configuration excluding the solar array. These moments are nearly constant and range from 0.1 to 0.27 n-m (0.07 to 0.2 ft-lb.). The moments due to the solar array alone range peak at about 0.9 n-m (0.66 ft-lb). about the Z-axis. The time integral of the aero moments shows the Z-axis to have the largest average value at -0.56 n-m (-0.4 ft-lb).

The gravity gradients and centripetal (gyroscopic) moments are shown in Figure 5-8. The Y-axis components show significant values while the X and Z-axis values are insignificant. The large Y moment values are attributable to the 12 deg principal axis misalignment (Table 2-4) about the Y axis for the example configuration. The oscilating character of the plots results from orbit perturbations due to the oblateness of the earth. The sum of the Y-axis gravity gradient and centripetal moments was about 66 n-m (48 ft-lb). As shown in Section 5.2, these moments result in large propellant usage rates for attitude control and reorienting to reduce these moments is required. The third orientation (Table 2-6) rotates the vehicle 12.1 deg about the Y-axis and greatly reduces the gravity gradient and centripetal moments.

5.2 ORBIT KEEPING AND ATTITUDE CONTROL RCS IMPULSE AND PROPELLANT REQUIREMENTS

This section contains a summary of the results for the 36 cases that were investigated as part of this orientation study. The data consists of average aero drag force and average aero, gravity gradient, and centripetal moments. Also included are RCS impulse requirements for 30 days for orbit keeping and attitude control for each case. These impulses were summed to provide a total impulse requirement which was used to calculate propellant mass requirements for a 30-day period. Hydrogen/oxygen RCS thrusters with a gIsp of 3920 m/sec (Isp = 400 sec) were assumed.

5.2.1 Orbit Keeping Impulse

Tables 5-1 through 5-4 define the average aerodynamic drag force and Tables 5-5 through 5-8 show the drag force impulse per 30 days for each configuration. Certain facts about the data are evident. They are:

A. The average drag force increases with configuration number (see Section 2.1),

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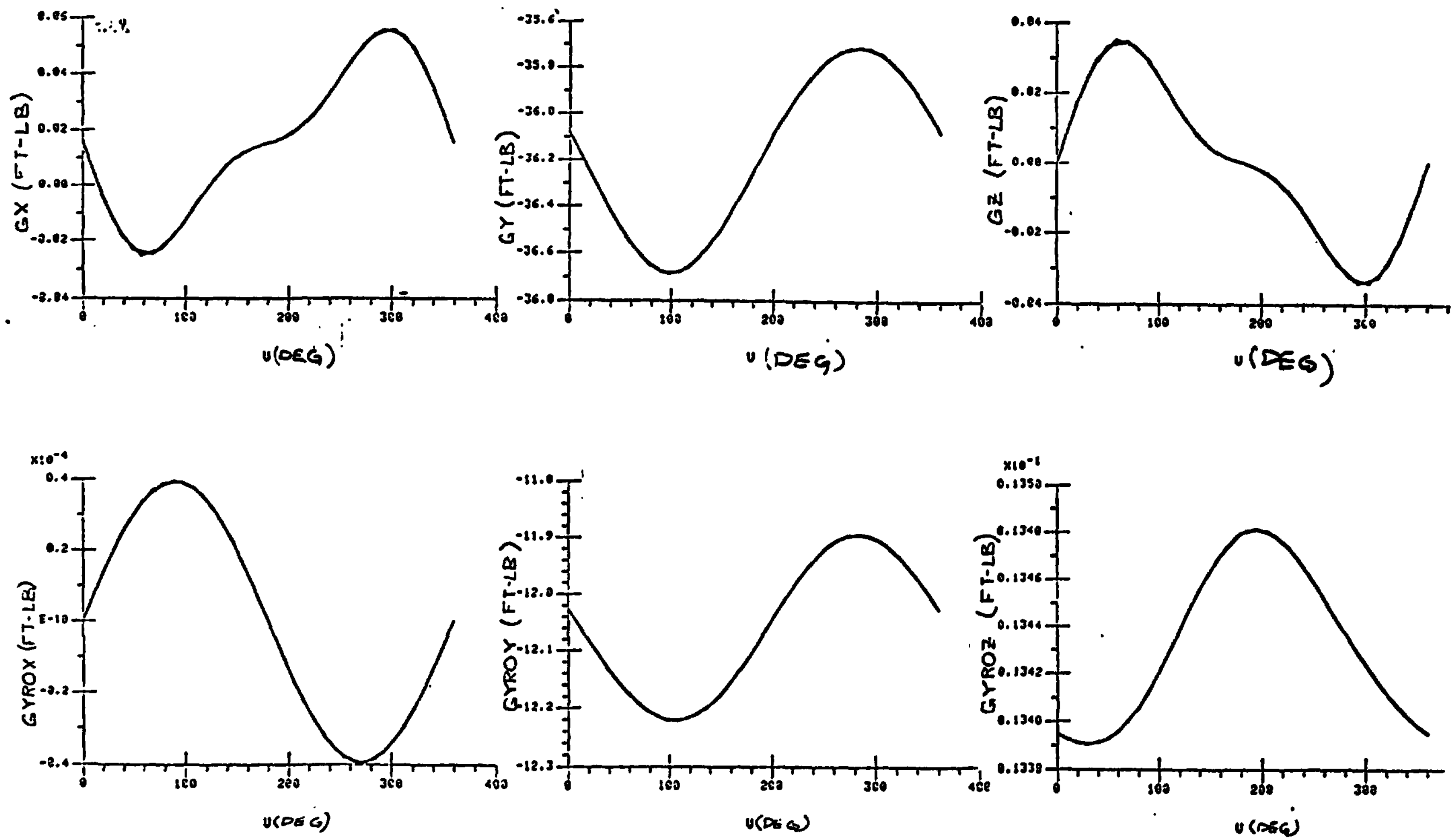

Figure 5-8. Gravity Gradient and Centripetal Moment Histories, Example Case

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Table 5-1

AVERAGE AERODYNAMIC DRAG FORCE SCB ONLY CONFIGURATION NO. 1

	Orientation	Drag Force** (n)		
		β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	0.023	0.019	0.005
2	XPOP, YAVV, ZDN	0.031	0.027	0.013
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	0.032	0.027	0.014

*β = Orbit plane to sun vector angle (deg)
**Time averaged over four orbits

Table 5-2

AVERAGE AERODYNAMIC DRAG FORCE SCB + 30-METER RADIOMETER CONFIGURATION NO. 2

	Orientation	Drag Force** (n)		
		β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	0.031	0.027	0.013
2	XPOP, YAVV, ZDN	0.039	0.035	0.023
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	0.039	0.037	0.022

*β = Orbit plane to sun vector angle (deg)
**Time averaged over four orbits

Table 5-3

AVERAGE AERODYNAMIC DRAG FORCE SCB + ORBITER CONFIGURATION NO. 3

	Orientation	Average** Drag Force (N)		
		β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	0.036	0.034	0.021
2	XPOP, YAVV, ZDN	0.040	0.036	0.023
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	0.040	0.036	0.023

*β = Orbit plane to sun vector angle (deg)
**Time averaged over four orbits

Table 5-4

AVERAGE AERODYNAMIC DRAG FORCE SCB + ORBITER + 30-METER RADIOMETER CONFIGURATION NO. 4

	Orientation	Average* Drag Force (N)		
		β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	0.045	0.042	0.030
2	XPOP, YAVV, ZDN	0.047	0.044	0.032
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	0.047	0.044	0.031

*β = Orbit plane to sun vector angle (deg)
**Averaged over 4 orbits

Table 5-5

AERODYNAMIC DRAG IMPULSE SCB ONLY
CONFIGURATION NO. 1

	Orientation	Impulse (n-sec/30 days)		
		β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	6.0×10^4	4.9×10^4	1.3×10^4
2	XPOP, YAVV, ZDN	8.0×10^4	7.0×10^4	3.4×10^4
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	8.3×10^4	7.0×10^4	3.6×10^4

*β = Orbit plane to sun vector angle (deg)

Table 5-6

AERODYNAMIC DRAG IMPULSE SCB + 30-METER
RADIOMETER CONFIGURATION NO. 2

	Orientation	Impulse (n-sec/30 days)		
		β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	8.0×10^4	7.0×10^4	3.4×10^4
2	XPOP, YAVV, ZDN	1.0×10^5	9.1×10^4	6×10^4
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	1.0×10^5	9.6×10^4	5.7×10^4

*β = Orbit plane to sun vector Angle (deg)

Table 5-7

AERODYNAMIC DRAG IMPULSE SCB + ORBITER CONFIGURATION NO. 3

	Orientation	Impulse (n-sec/30 days)		
		β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	9.3×10^4	8.8×10^4	5.4×10^4
2	XPOP, YAVV, ZDN	10.4×10^4	9.3×10^4	6.0×10^4
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	10.4×10^4	9.3×10^4	6.0×10^4

*β = Orbit plane to sun vector angle (deg)

Table 5-8

AERODYNAMIC DRAG IMPULSE SCB + ORBITER + 30-METER RADIOMETER CONFIGURATION NO. 4

	Orientation	Impulse (n-sec/30 days)		
		β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	1.2×10^5	1.1×10^5	7.8×10^4
2	XPOP, YAVV, ZDN	1.2×10^5	1.1×10^5	8.3×10^4
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	1.2×10^5	1.1×10^5	8.0×10^4

*β = Orbit plane to sun vector angle (deg)

B. The average drag force decreases with increasing β angle,

C. The YPOP orientation has the lowest average drag force, and

D. The XPOP and X_pPOP orientations have essentially the same average drag force.

The first observation above is predictable based on the aero coefficient data of Table 2-5. The force coefficient along the axis of the velocity vector is larger for each successive configuration. Note that the orbiter has a larger Y axis force coefficient than the radiometer for the YAVV orientation in spite of the larger radiometer projected area to the air stream. The angle of incidence on the radiometer surface is significantly less than 90 deg on most of the radiometer which accounts for its relatively low force coefficient.

The β-angle dependence (A., preceding) is due to the solar array having higher average angles of incidence with lower β angles. Consider the following: for $\beta = 0$, the solar array reaches an angle of incidence of 90 deg twice each orbit while at a β of 90 deg, the array remains at an angle of incidence of zero throughout the whole orbit. Intermediate β angles result in average angles of incidence between the previous mentioned. The YPOP orientation has the lowest drag force in spite of the large orbiter wing area perpendicular to the air stream because the SCB force coefficient is about 65 percent less for the YPOP orientation than for XPOP. The fourth statement preceding (D.) results from the fact that the Y force coefficient has the same magnitude independent of whether the orientation is YOVV or YAVV. In going from XPOP to X_pPOP, the vehicle was rotated about the Y-axis and since the Y-axis was parallel to the velocity vector, the rotation had no effect on the aero force coefficients.

The aero drag force impulse values were calculated by multiplying the average drag force by the number of seconds in 30 days. The results are contained in Tables 5-5 through 5-8.

5.2.2 Disturbing Moment Impulse

The disturbing moment values for each configuration are summarized in Tables 5-9 through 5-12. Gravity gradient, centripetal gradient, and aero

Table 5-9

AVERAGE DISTURBING MOMENT SUMMARY SCB ONLY CONFIGURATION NO. 1

Orientation	Disturbing Torque	Bias** Moment (n-m) Gravity Gradient	Centri-petal	Aerodynamic* $\beta = 0$	$\beta = 31.8$	$\beta = -78.2$
	X	0	0	0	-0.01	0
1 XAVV, YPOP, ZDN	Y	4.8	0	0.02	0.01	-0.03
	Z	0	0	0	-0.01	0
	X	0	0	-0.04	-0.03	0.01
2 XPOP, YAVV, ZDN	Y	4.8	1.61	0	-0.01	0
	Z	0	0	-0.04	-0.03	0.01
	X_p	0	0	0.04	0.03	-0.01
3 X_pPOP, Y_pOVV, Z_pDN	Y_p	0.01	0	0	0	0
(Principal Inertia Axes)	Z_p	0	0	0.04	0.03	-0.01

*β = Orbit plane to sun vector angle (deg)
**Time averaged over four orbits

Table 5-10

AVERAGE DISTURBING MOMENT SUMMARY SCB + 30-METER RADIOMETER CONFIGURATION NO. 2

Orientation	Disturbing Torque	Average** Disturbing Moment (n-m) Gravity Gradient	Centri-petal	Aerodynamic* $\beta = 0$	$\beta = 31.8$	$\beta = -78.2$
	X	0	0	0	0	0
1 XAVV, YPOP, ZDN	Y	20.0	0	-0.03	-0.03	-0.03
	Z	0	0	0	0.02	-0.01
	X	0	0	0.02	0.02	0.03
2 XPOP, YAVV, ZDN	Y	20.0	6.7	0.13	0.15	0.16
	Z	0	0	-0.01	-0.05	-0.14
	X_p	0	0	-0.02	-0.02	-0.03
3 X_pPOP, Y_pOVV, Z_pDN	Y_p	0.01	0.01	-0.16	-0.15	-0.16
(Principal Inertia Axes)	Z_p	0	0	0.01	0.04	0.14

*β = Orbit plane to sun vector angle (deg)
**Time averaged over four orbits

Table 5-11

AVERAGE DISTURBING MOMENT SUMMARY
SCB + ORBITER CONFIGURATION NO. 3

Orientation	Disturbing Torque	Bias** Moment (n-m) Gravity Gradient	Centripetal	Aerodynamic* $\beta = 0$	$\beta = 31.8$	$\beta = -78.2$
	X	0.02	0	0	0.02	0
1 XAVV, YPOP, ZDN	Y	-45	0	-0.10	-0.10	0
	Z	0	-0.01	0	-0.05	0.01
	X	0.02	0	0.22	0.19	0.10
2 XPOP, YAVV, ZDN	Y	-45	-15	0.02	0.01	-0.01
	Z	0	0.01	-0.45	-0.37	-0.12
	X_p	0	0	-0.22	-0.17	-0.10
3 X_pPOP, Y_pOVV, Z_pDN	Y_p	-0.16	-0.05	0.02	0.01	0
(Principal Inertia Axes)	Z_p	0	0.01	0.44	0.36	0.10

*β = Orbit plane to sun vector angle (deg)
**Time averaged over four orbits

Table 5-12

AVERAGE DISTURBING MOMENT SUMMARY
SCB + ORBITER + 30-METER RADIOMETER CONFIGURATION NO. 4

Orientation	Disturbing Torque	Bias** Moment (n-m) Gravity Gradient	Centripetal	Aerodynamic* $\beta = 0$	$\beta = 31.8$	$\beta = -78.2$
	X	0.02	0.01	0	0.02	0
1 XAVV, YPOP, ZDN	Y	-50	0	-0.16	-0.15	-0.05
	Z	0	-0.02	0	-0.03	0
	X	0.02	0	0.26	0.24	0.15
2 XPOP, YAVV, ZDN	Y	-50	-16	0.24	0.25	0.24
	Z	0	0.02	-0.60	-0.56	-0.42
	X_p	0.01	0	-0.26	-0.24	-0.16
3 X_pPOP, Y_pOVV, Z_pDN	Y_p	0.26	0.08	-0.21	-0.26	-0.26
(Principal Inertia Axes)	Z_p	0	0.02	0.59	0.55	0.40

*β = Orbit plane to sun vector angle (deg)
**Time averaged over four orbits

moments for each vehicle axis are shown separately. The gravity gradient and centripetal gradient moments are dominated by the Y-axis component values because of the principal axes misalignment about the vehicle Y-axis. The gravity gradient orientations (Orientation No. 3) result in much reduced gravity/centripetal gradient moments, though not zero, especially about the Y-axis. The average gravity/centripetal gradient moments could have been made essentially zero by very accurate orientation definitions that require precision attitude pointing accuracies. For example, the 0.26 n-m Y-axis gravity gradient moment for Orientation No. 3 of the SCB + Orbiter + 30-meter radiometer configuration (Table 5-12) results from only a 0.06 deg attitude error from the theoretical zero gravity gradient moment orientation. An accuracy of 0.06 deg is considered tight from an attitude control system design viewpoint. The gravity/centripetal gradient moment data presented herein is of an illustrative nature and the Orientation No. 3 values do not reflect an actual attitude controller design. One of the primary design drivers for an SCB attitude controller will be to minimize the net disturbing moments on the system for extended periods of time. Note that the gravity/centripetal gradient moments increase with configuration number (increasing mass) for all orientations.

The aerodynamic moments are small compared to the gravity/centripetal gradient moments for all be Orientation No. 3. The larger configurations tend to have larger aero moments as expected and the Z component of aero moment exceeds 0.5 n-m for the XPOP orientations for the maximum configuration (Table 5-12). The aero moments and gravity/centripetal gradient moments nearly cancel each other in the Y-axis of configuration 4 for Orientation No. 3 (Table 5-12). The relatively large aero moments about the Z-axis for the configurations which includes the Orbiter results from the large mass of the Orbiter relative to the SCB and SCB + 30-meter radiometer. The large Orbiter mass places the total configuration center of mass near the Orbiter which results in a large aerodynamic lever arm for the solar array and radiometer and a short aerodynamic level arm for the Orbiter. For the XPOP orientations (No. 2 and 3), a relatively large net aero moment about the Z-axis results.

The net disturbing moments acting on the vehicle are shown in Tables 5-13 through 5-16 along with the corresponding moment impulses. For Orientations No. 1 and 2, the gravity/centripetal gradient moments dominate as expected. For Orientation No. 3, the net moments generally increase with configuration mass. However, as mentioned above, the Y-axis net moment for the maximum configuration (4) was relatively small due to cancellation of the aero and gravity/centripetal gradient moments (Table 5-16).

The moment impulses shown in Tables 5-13 through 5-16 may be compared to control moment gyro (CMG) capabilities to gain an intuitive understanding of their magnitude. The Bendix 6000H CMG has a nominal moment impulse capability of 8200 n-m-sec. The largest moment impulse observed in this study was 1.7×10^8 n-m-sec for 30 days for the maximum configuration (Table 5-16, Orientation No. 2). Assuming three active CMG's, the CMG's would need desaturation every 6 min. Considering the more realistic Orientation No. 3 with 1.1×10^6 n-m-sec about the three axes, the desaturation time interval for the same three CMG becomes a reasonable 16 hours. The validity of the last calculation depends on the ability of the attitude controller to minimize net disturbing moments.

Calculating the RCS impulse required to cancel the disturbance moments required selecting thruster locations and a simple thruster select logic. The thrusters were located at the ends of the core module and at a radius of 2.29m from the centerline. The thrusters were assumed to fire in pairs, forming pure couples (moment without any net lateral force). Each pair provided control moment about the X, Y, or Z axis. The attitude controller was assumed to limit the motion to orbital angular rate and no other dynamic effects were considered. The use of a couple concept allowed the control moment to be independent of center of mass location. For a couple, the control lever arm length is on-half the distance between the firing thrusters. For the thruster locations selected, the lever arm for X-axis (roll) control moment was $L_x = 2.29$ m while for the Y and Z-axes (pitch and yaw), $L_y = L_z = 7.6$ m. Using these lever arms, the thruster impulse values shown in Tables 5-17 through 5-20 were calculated. Because of the shorter control lever arm for roll control, the X-axis impulse values increase in significance relative to pitch and yaw. This impulse will be required either to desaturate the CMG or to control if no CMG's are used.

Table 5-13

NET DISTURBING MOMENT AND MOMENT IMPULSE SUMMARY
SCB ONLY CONFIGURATION NO. 1

Orientation		Net Moment (n-m) (Moment Impulse (10^5 n-m-sec))		
		β = 0*	β = 31.8*	β = -78.2*
	X	0 (0)	-0.01 (0.26)	0 (0)
1 XAVV, YPOP, ZDN	Y	4.82 (125)	4.81 (125)	4.77 (124)
	Z	0 (0)	-0.01 (0.26)	0 (0)
	X	-0.04 (1.0)	-0.03 (0.78)	0.01 (0.26)
2 XPOP, YAVV, ZDN	Y	6.4 (166)	6.4 (166)	6.4 (166)
	Z	-0.04 (1.0)	-0.03 (0.78)	0.01 (0.26)
	X_p	0.04 (1.0)	0.03 (0.78)	-0.01 (0.26)
3 X_pPOP, Y_pOVV, Z_pDN	Y_p	0.01 (0.26)	0.01 (0.26)	0.01 (0.26)
(Principal Inertia Axes)	Z_p	0.04 (1.0)	0.03 (0.78)	-0.01 (0.26)

*β = Orbit plane to sun vector angle (deg)

Table 5-14

NET DISTURBING MOMENT AND MOMENT IMPULSE SUMMARY
SCB + 30-METER RADIOMETER CONFIGURATION NO. 2

Orientation		Net Moment (n-m) (Moment Impulse (10^5 n-m-sec))		
		β = 0*	β = 31.8*	β = -78.2*
	X	0 (0)	0 (0)	0 (0)
1 XAVV, YPOP, ZDN	Y	20 (518)	20 (518)	20 (518)
	Z	0 (0)	0.02 (0.52)	-0.01 (0.26)
	X	0.02 (0.52)	0.02 (0.52)	0.03 (0.78)
2 XPOP, YAVV, ZDN	Y	26.8 (695)	26.9 (697)	26.9 (697)
	Z	-0.01 (0.26)	-0.05 (1.3)	-0.14 (3.6)
	X_p	-0.02 (0.52)	-0.02 (0.26)	-0.03 (0.78)
3 X_pPOP, Y_pOVV, Z_pDN	Y_p	-0.14 (3.6)	-0.13 (3.4)	-0.14 (3.6)
(Principal Inertia Axes)	Z_p	0.01 (0.26)	0.04 (1.0)	0.14 (3.6)

*β = Orbit Plane to sun vector angle (deg)

Table 5-15

NET DISTURBING MOMENT AND MOMENT IMPULSE SUMMARY
SCB + ORBITER CONFIGURATION NO. 3

Orientation		Net Moment (n-m) (Moment Impulse (10^5 n-m-sec))		
		β = 0*	β = 31.8*	β = -78.2*
	X	0.02 (0.52)	0.04 (1.0)	0.02 (0.52)
1 XAVV, YPOP, ZDN	Y	-45.1 (1170)	-45.1 (1170)	-45.0 (1170)
	Z	-0.01 (0.26)	-0.06 (1.6)	0 (0)
	X	0.24 (6.2)	0.21 (5.4)	0.12 (3.1)
2 XPOP, YAVV, ZDN	Y	-60 (1560)	-60 (1560)	-60 (1560)
	Z	-0.44 (11.4)	-0.36 (9.3)	-0.11 (2.9)
	X_p	-0.22 (5.7)	-0.17 (4.4)	-0.10 (2.6)
3 X_pPOP, Y_pOVV, Z_pDN	Y_p	-0.19 (4.9)	-0.20 (5.7)	-0.21 (5.4)
(Principal Inertia Axes)	Z_p	0.45 (11.7)	0.37 (9.6)	0.11 (2.9)

*β = Orbit plane to sun vector angle (deg)

Table 5-16

NET DISTURBING MOMENT AND MOMENT IMPULSE SUMMARY
SCB + ORBITER + 30-METER RADIOMETER CONFIGURATION NO. 4

Orientation		Net Moment (n-m) (Moment Impulse (10^5 n-m-sec))		
		β = 0*	β = 31.8*	β = -78.2*
	X	0.03 (0.78)	0.05 (1.3)	0.03 (0.78)
1 XAVV, YPOP, ZDN	Y	-50.2 (1,300)	-50.2 (1,300)	-50.1 (1,300)
	Z	-0.02 (0.52)	-0.05 (1.3)	-0.02 (0.52)
	X	0.28 (7.3)	0.26 (6.7)	0.17 (4.4)
2 XPOP, YAVV, ZDN	Y	-66.2 (1,720)	-66.3 (1,720)	-66.2 (1,720)
	Z	-0.58 (1.5)	-0.54 (14)	-0.40 (10)
	X_p	-0.25 (6.5)	-0.23 (6.0)	-0.15 (3.9)
3 X_pPOP, Y_pOVV, Z_pDN	Y_p	0.13 (3.4)	0.08 (2.1)	0.08 (2.1)
(Principal Inertia Axes)	Z_p	0.61 (16)	0.57 (15)	0.42 (11)

*β = Orbit plane to sun vector angle (deg)

Table 5-17

ATTITUDE CONTROL IMPULSE
SCB ONLY CONFIGURATION NO. 1

	Orientation		Impulse (n-sec/30 Days) β = 0*	β = 31.8*	β = -78.2*
		X	0	1.1×10^4	0
1	XAVV, YPOP, ZDN	Y	1.6×10^6	1.6×10^6	1.6×10^6
		Z	0	3.4×10^3	0
		X	4.5×10^4	3.4×10^4	1.1×10^4
2	XPOP, YAVV, ZDN	Y	2.2×10^6	2.2×10^6	2.2×10^6
		Z	1.4×10^4	1.0×10^4	3.4×10^3
		X_p	4.5×10^4	3.4×10^4	1.1×10^4
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	Y_p	3.4×10^3	3.4×10^3	3.4×10^3
		Z_p	1.4×10^4	1.0×10^3	3.4×10^3

*β = Orbit plane to sun vector angle (deg)

Table 5-18

ATTITUDE CONTROL IMPULSE
SCB + 30-METER RADIOMETER CONFIGURATION NO. 2

	Orientation		Impulse (n-sec/30 Days) β = 0*	β = 31.8*	β = -78.2*
		X	0	0	0
1	XAVV, YPOP, ZDN	Y	6.8×10^6	6.8×10^6	6.8×10^6
		Z	0	6.8×10^3	3.4×10^3
		X	2.3×10^4	2.3×10^4	3.4×10^4
2	XPOP, YAVV, ZDN	Y	9.1×10^6	9.2×10^6	9.2×10^6
		Z	3.4×10^3	1.7×10^4	4.8×10^4
		X_p	2.3×10^4	2.3×10^4	3.4×10^4
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axis)	Y_p	4.8×10^4	4.4×10^4	4.8×10^4
		Z_p	3.4×10^3	1.4×10^4	4.8×10^4

*β = Orbit plane to sun vector angle (deg)

Table 5-19

ATTITUDE CONTROL IMPULSE
SCB + ORBITER CONFIGURATION NO. 3

Orientation			Impulse (n-sec/30 Days) β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	X	2.3×10^4	4.5×10^4	2.3×10^4
		Y	1.5×10^7	1.5×10^7	$.5 \times 10^7$
		Z	3.4×10^3	2.0×10^4	0
2	XPOP, YAVV, ZDN	X	2.7×10^5	2.4×10^5	1.4×10^5
		Y	2.0×10^7	2.0×10^7	2.0×10^7
		Z	1.5×10^5	1.2×10^5	3.8×10^4
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	X_p	2.5×10^5	1.9×10^5	1.1×10^5
		Y_p	6.5×10^4	6.8×10^4	7.2×10^4
		Z_p	1.5×10^5	1.3×10^5	3.8×10^4

*β = Orbit plane to sun vector angle (deg)

Table 5-20

ATTITUDE CONTROL IMPULSE
SCB + ORBITER + 30-METER RADIOMETER CONFIGURATION NO. 4

Orientation			Impulse (n-sec/30 Days) β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	X	3.4×10^4	5.7×10^4	3.4×10^4
		Y	1.7×10^7	1.7×10^7	1.7×10^7
		Z	6.8×10^3	1.7×10^4	6.8×10^3
2	XPOP, YAVV, ZDN	X	3.2×10^5	2.9×10^5	1.9×10^5
		Y	2.3×10^7	2.3×10^7	2.3×10^7
		Z	2.0×10^5	1.8×10^5	1.4×10^5
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	X_p	2.8×10^5	2.6×10^5	1.7×10^5
		Y_p	4.4×10^4	2.7×10^4	2.7×10^4
		Z_p	2.1×10^5	1.9×10^5	1.4×10^5

*β = Orbit plane to sun vector angle (deg)

It should be noted that these RCS impulse values do not reflect any impulse for maneuvering, docking, construction disturbances, or attitude limit cycling. The impulse values in Tables 5-17 through 5-20 are solely for countering the disturbance moments discussed in this appendix. For the axes where the disturbing moment changes sign, additional RCS impulse will be required if momentum storage devices are not used.

5.2.3 Total RCS Impulse and Propellant Requirements

The RCS impulse requirements for orbit keeping and disturbing moment cancellation discussed in Section 5.2.1 and 5.2.2 were summed to generate the total RCS impulse requirements shown in Tables 5-21 through 5-24. Implicit in the above procedure were the assumptions that the attitude control impulse was the sum of the pitch, yaw, and roll requirements and that the orbit keeping impulse was equal to the aerodynamic drag force impulse. A more optimum thruster placement and thruster select logic could have reduced the total impulse requirement to less than the sum of the parts mentioned, but, for the purpose of this study, the simple RCS thruster concept was adequate.

The propellant mass requirements are given in Tables 5-25 through 5-28. They were calculated assuming a hydrogen/oxygen RCS propellant with a gIsp of 3920 m/sec (Isp = 400 sec). The propellant mass requirements generally increase with increasing configuration mass and with decreasing β-angle. The large propellant masses associated with Orientations No. 1 and 2 resulted from the large gravity/centripetal gradient moments. Orbit keeping and attitude control each had significant contributions for Orientation No. 3. Actual propellant requirements should be more on the order of those shown for Orientation No. 3 since net disturbing moments will be minimized by the orientation chosen. Additional propellant for maneuvering, docking, and limit cycling will also be required.

Table 5-29 summarizes the propellant mass requirements for Orientation No, 3 for all four configurations as a function of β angle. The largest propellant mass requirement of 167 kg/30 days corresponds to the largest configuration for a β angle of zero. The lowest propellant usage rate corresponds to the SCB only configuration with values of 14 to 37 kg/30 days.

Table 5-21

TOTAL RCS IMPULSE REQUIREMENTS
SCB ONLY CONFIGURATION NO. 1

	Orientation	Impulse (n-sec/30 Days) β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	1.60×10^6	1.66×10^6	1.61×10^6
2	XPOP, YAVV, ZDN	2.34×10^6	2.31×10^6	2.25×10^6
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	1.45×10^5	1.08×10^5	5.38×10^4

*β = Orbit plane to sun vector angle (deg)

Table 5-22

TOTAL RCS IMPULSE REQUIREMENTS
SCB + 30-METER RADIOMETER CONFIGURATION NO. 2

	Orientation	Impulse (n-sec/30 Days) β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	6.88×10^6	6.88×10^6	6.84×10^6
2	XPOP, YAVV, ZDN	9.23×10^6	9.33×10^6	9.34×10^6
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	1.74×10^5	1.77×10^5	1.87×10^5

*β = Orbit plane to sun vector angle (deg)

Table 5-23

TOTAL RCS IMPULSE REQUIREMENTS
SCB + ORBITER CONFIGURATION NO. 3

	Orientation	Impulse (n-sec/30 Days)		
		β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	1.51×10^7	1.52×10^7	1.51×10^7
2	XPOP, YAVV, ZDN	2.05×10^7	2.05×10^7	2.02×10^7
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	5.69×10^5	4.81×10^5	2.80×10^5

*β = Orbit plane to sun vector angle (deg)

Table 5-24

TOTAL RCS IMPULSE REQUIREMENTS
SCB + ORBITER + 30-METER RADIOMETER CONFIGURATION NO. 4

	Orientation	Impulse (n-sec/30 Days)		
		β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	1.72×10^7	1.72×10^7	1.71×10^7
2	XPOP, YAVV, ZDN	2.36×10^7	2.36×10^7	2.34×10^7
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	6.54×10^5	5.87×10^5	4.17×10^5

*β = Orbit plane to sun vector angle (deg)

Table 5-25

RCS PROPELLANT REQUIREMENTS
SCB ONLY CONFIGURATION NO. 1

	Orientation	Attitude Control Plus Orbit Keeping Propellant (kg/30 Days)		
		β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	423	423	411
2	XPOP, YAVV, ZDN	597	589	574
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)**	37	28	14

*β = Orbit plane to sun vector angle (deg)
**8 deg noseup from geometrical axes

Table 5-26

SCB + 30-METER RADIOMETER CONFIGURATION NO. 2

	Orientation	RCS Propellant (kg/30 Days)		
		β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	1,760	1,760	1,740
2	XPOP, YAVV, ZDN	2,350	2,380	2,380
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)**	44	45	48

*β = Orbit plane to sun vector angle (deg)
**11 deg noseup from geometrical axes

Table 5-27

RCS PROPELLANT REQUIREMENTS
SCB + ORBITER CONFIGURATION NO. 3

	Orientation	Attitude Control Plus Orbit Keeping Propellant (kg/30 Days)		
		β = 0*	β = 31.8*	β = -78.2*
1	XAVV, YPOP, ZDN	3,850	3,880	3,850
2	XPOP, YAVV, ZDN	5,230	5,230	5,150
3	X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)**	145	123	71

*β = Orbit plane to sun vector angle (deg)
**29 deg nosedown from geometrical axes

Table 5-28

RCS PROPELLANT REQUIREMENTS
SCB + ORBITER + 30-METER RADIOMETER CONFIGURATION NO. 4

Orientation	Attitude Control Plus Orbit Keeping Propellant (kg/30 Days)		
	β = 0*	β = 31.8*	β = -78.2*
XAVV, YPOP, ZDN	4,390	4,390	4,360
XPOP, YAVV, ZDN	6,020	6,020	5,970
X_pPOP, Y_pOVV, Z_pDN (Principal Inertia Axes)	167	150	106

*β = Orbit plane to sun vector angle (deg)
**12 deg nosedown from geometrical axes

Table 5-29

PROPELLANT REQUIREMENTS SUMMARY
X_pPOP, Y_pOVV, AND Z_pDN ORIENTATION

Configuration	Propellant (kg/30 Days)		
	β = 0*	β = 31.8*	β = -78.2*
SCB Only	37	28	14
SCB + Radiometer	44	45	48
SCB + Orbiter	145	123	71
SCB + Orbiter + Radiometer	167	150	106

*β = Orbit plane to sun vector angle (deg)

5.3 SOLAR CELL SHADOWING ANALYSIS

5.3.1 Vehicle Shadowing of Solar Cells

5.3.1.1 Orientation No. 1 (XAVV, YPOP, ZDN)

The results of the computer graphic shadowing analysis for the YPOP orientation with $\beta = 0$ are shown in Figure 5-9 in which the vehicle is pictured as viewed from the sun and the solar panels are oriented normal to the sun. Five orbital positions are shown, progressing from prenoon (negative θ) through noon ($\theta = 0$) to postnoon (positive θ). The first position shows the vehicle following orbital dawn, and indicates that Panel No. 2 is shadowed approximately 21 percent by the radiometer (which is on the sun side of the panel); Panel No. 1 is unshadowed. There is no shadowing of either panel for θ = 45 deg and 0 deg. For the position in which the vehicle is 45 deg past orbital noon, the Orbiter is on the sun side and both panels are shadowed approximately 6 percent by the Orbiter wings. In the last position (just before orbital dusk) both panels are shadowed approximately 7 percent by the Orbiter, primarily the cargo bay doors.

5.3.1.2 Orientation No. 2 (XPOP, YAVV, ZDN)

The results of the shadowing analysis for XPOP orientation are presented in Figure 5-10 for β = 0 deg and Figure 5-11 for β = -78.5 deg. For β = 0 deg, the vehicle orbit plane is depicted as normal to the plane of the paper. These views show that neither solar panel is shadowed by structural elements of the vehicle for any orbit position.

The results for β = -78.5 deg (Figure 5-10) with the vehicle at θ = -90 deg show that the Orbiter (on the sun side of the panels) shadows approximately 28 percent of solar panel No. 1; whereas panel No. 2 is unshadowed. It should be noted that there is no dawn or dusk for this orbit since it is entirely sunlit. At θ = -45 deg, the view indicates that panel No. 1 is still shadowed approximately 25 percent by the Orbiter; Panel No. 2 is just beginning to be shadowed by the Orbiter wing. At orbital noon, both panels are shadowed approximately 5 percent by the Orbiter wings and cargo bay doors. The conditions for θ = 45 deg and 90 deg are comparable to the conditions for θ = -45 deg and -90 deg except that panel No. 2 is now shadowed instead of panel No. 1.

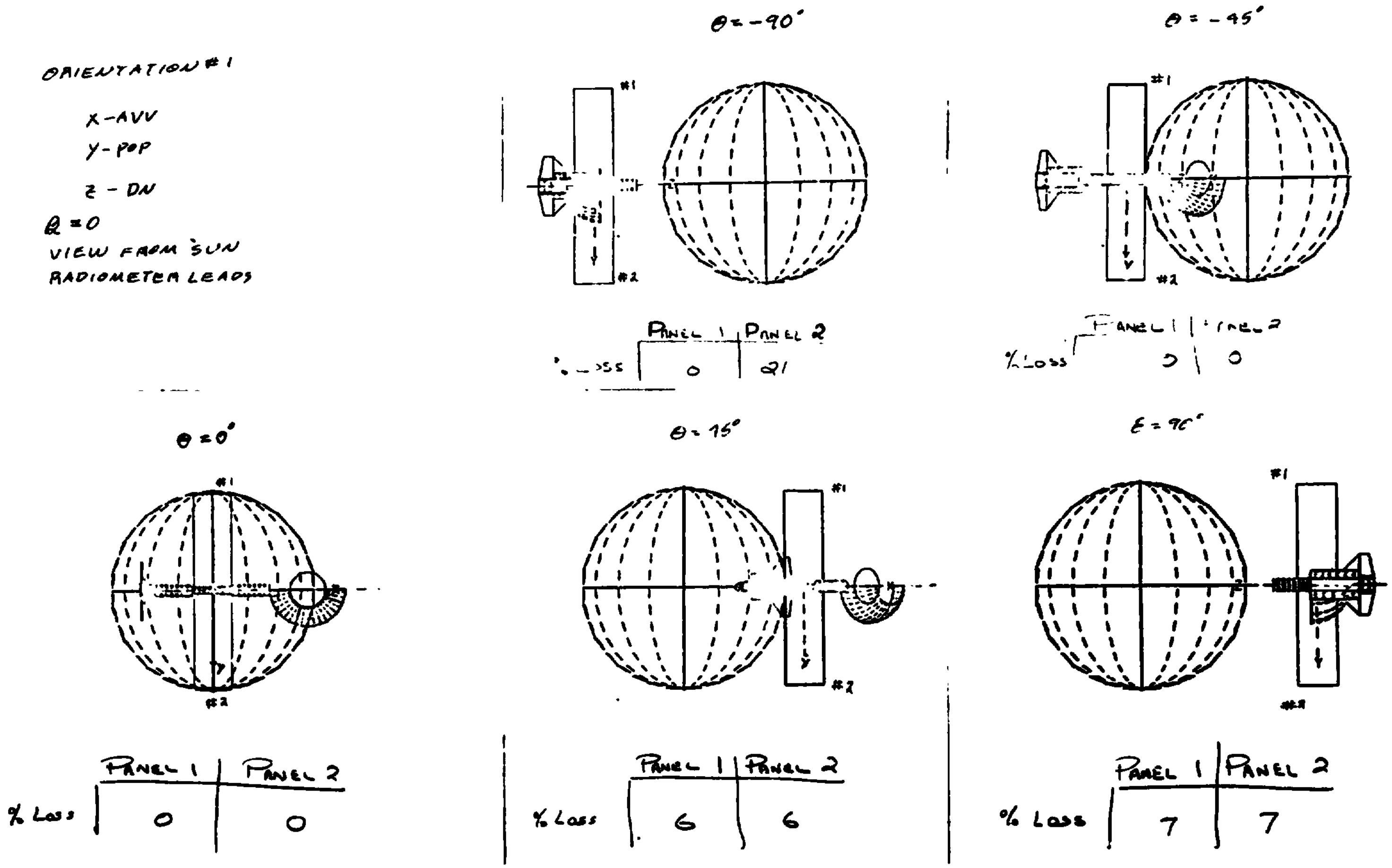

Figure 5-9. Vehicle Shadowing of Solar Cells – Orbiter + SCB + 30-Meter Radiometer

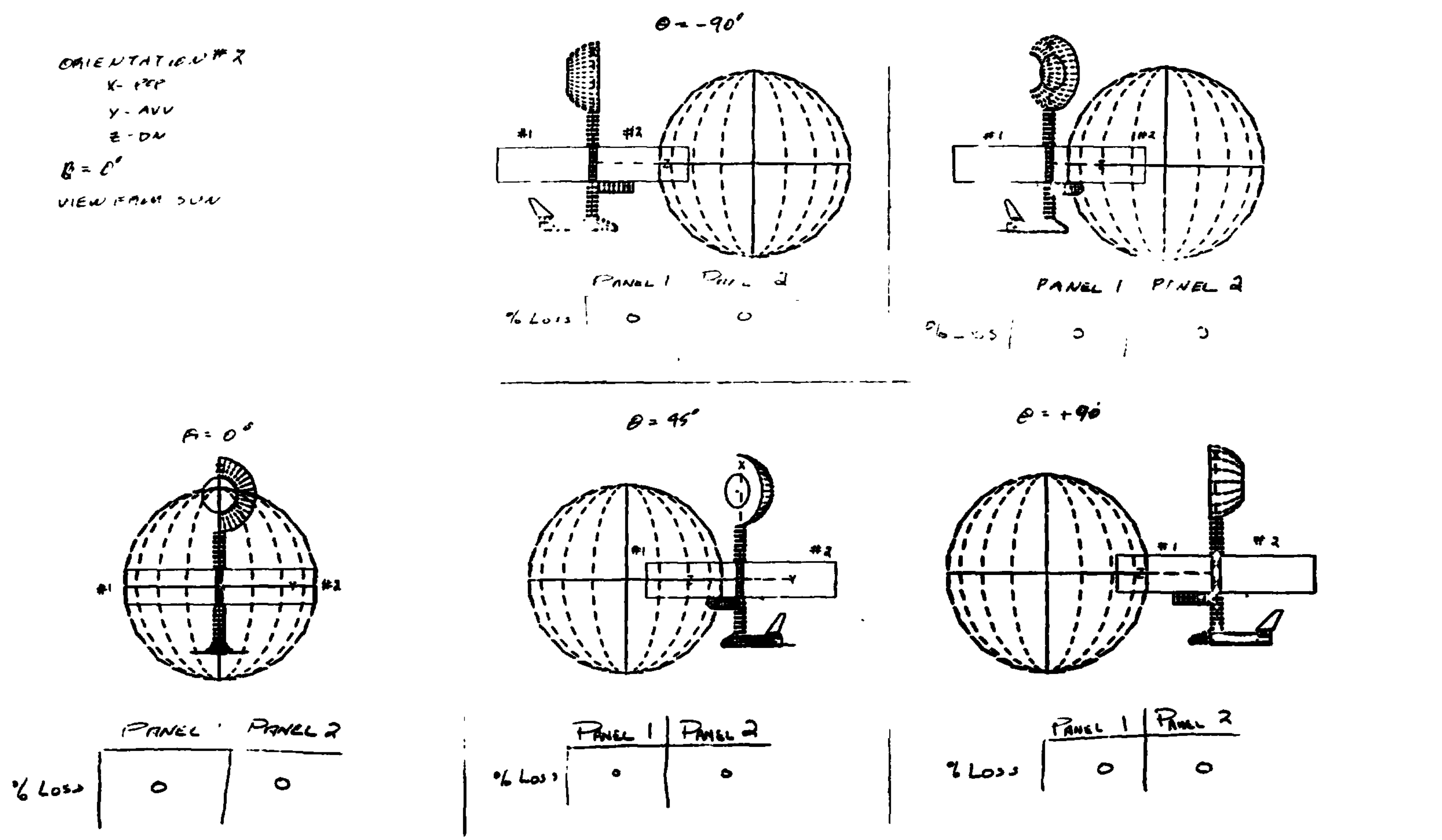

Figure 5-10. Vehicle Shadowing of Solar Cells — Orbiter + SCB + 30-Meter Radiometer

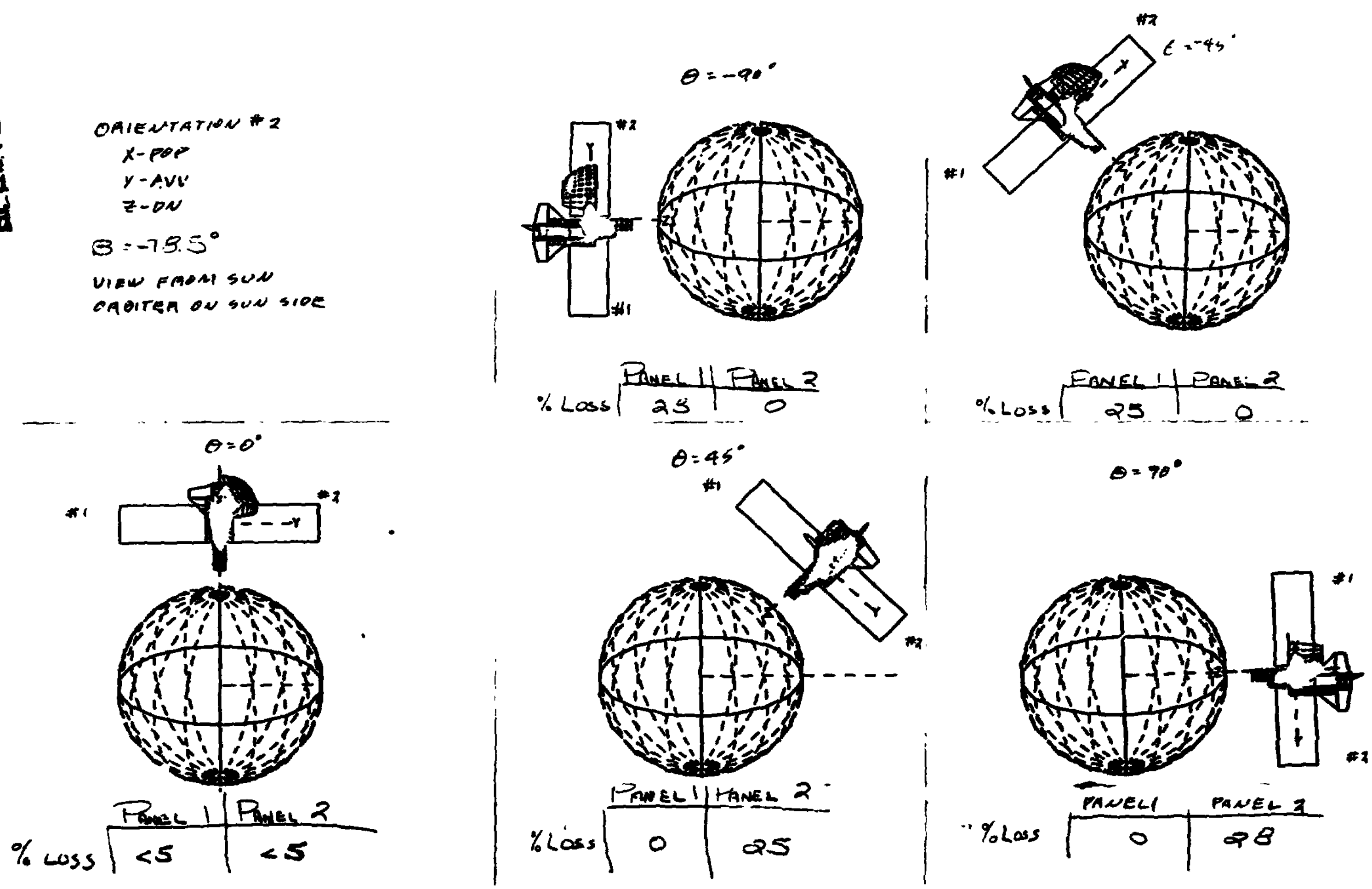

Figure 5-11. Vehicle Shadowing of Solar Cells – Orbiter + SCB + 30-Meter Radiometer

5.3.1.3 Analysis of Shadowing Data from the Vehicle

The effect of vehicle tilt about the Y-axis associated with Orientation No. 3 was reserved for later analytical effort. An analysis was performed on the data available from Sections 5.3.1.1 and 5.3.1.2 to determine general trends of solar cell shadowing by the vehicle. Additional data at β = -90 deg were determined by hand graphics in order to provide additional visibility on the variation with β. All the data were faired and time-averaged for the two panels over the sunlit portion of the orbit for a given β, and these averages for both orientations are given as a function of β in Figure 5-12. For Orientation No. 2, three data points permitted a fairing of the data based on qualitative judgment. In the case of Orientation No. 1, no such assumptions were made.

Although the data indicated in Figure 5-12 are incomplete, qualitative conclusions may be drawn. Orientation No. 2 (XPOP) indicates a significant, but not great, drop-off in illumination at the higher β-angles, but this should be tempered by the fact that the earth-shadowing is minimized at these angles. In the case of Orientation No. 1, the lower β-angles are more affected by vehicle-shadowing.

5.3.2 Earth-Shadowing Effects

The β-angle at which the vehicle in orbit sees the center of the sun at all times is given as function of altitude in Figure 5-13. It is indicated that at an altitude of 216 nmi (approximately 400 km), the β-angle for 100 percent viewing is 70.2 deg. Earth's atmospheric effects and the fact that the sun's mean diameter subtends an angle of 0.533 deg were neglected in this analysis.

The illumination efficiency associated with earth-shadowing for a 216 nmi (approximately 400 km) altitude orbit is given in Figure 5-14. Although the neglected effects of sun diameter and earth atmosphere tend to broaden the line, the trend is very clear. The increase in solar viewing at large β-angles is very significant. The values from Figure 5-14 were also used in determining the time spread for averaging the vehicle-shadowing effects.

An evaluation of the time-history of β-angle and the likelihood of exceeding a given β-angle were determined. Figure 5-15 provides a history of β-angle

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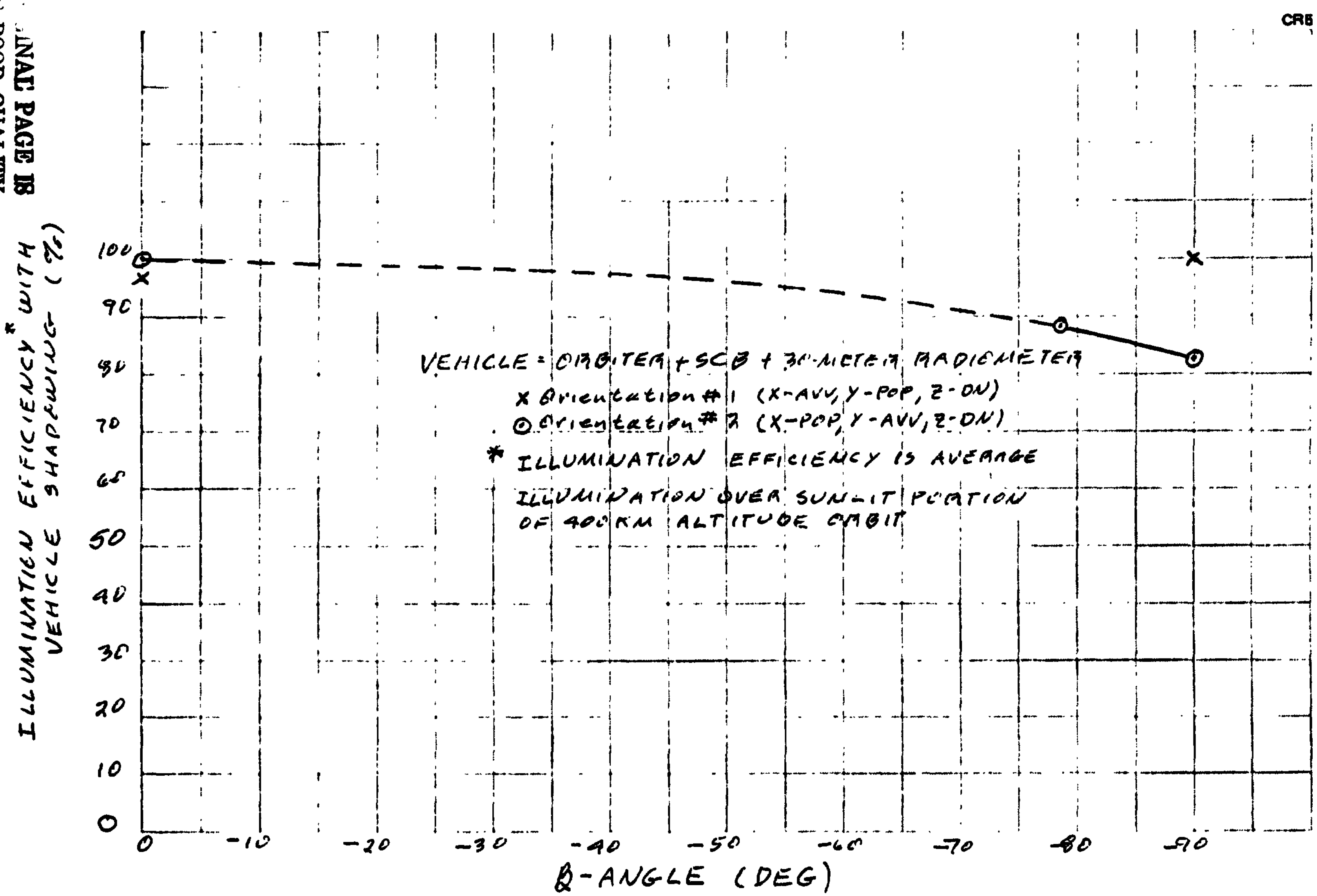

Figure 5-12. Solar Cell Illumination Efficiency with Vehicle Shadowing

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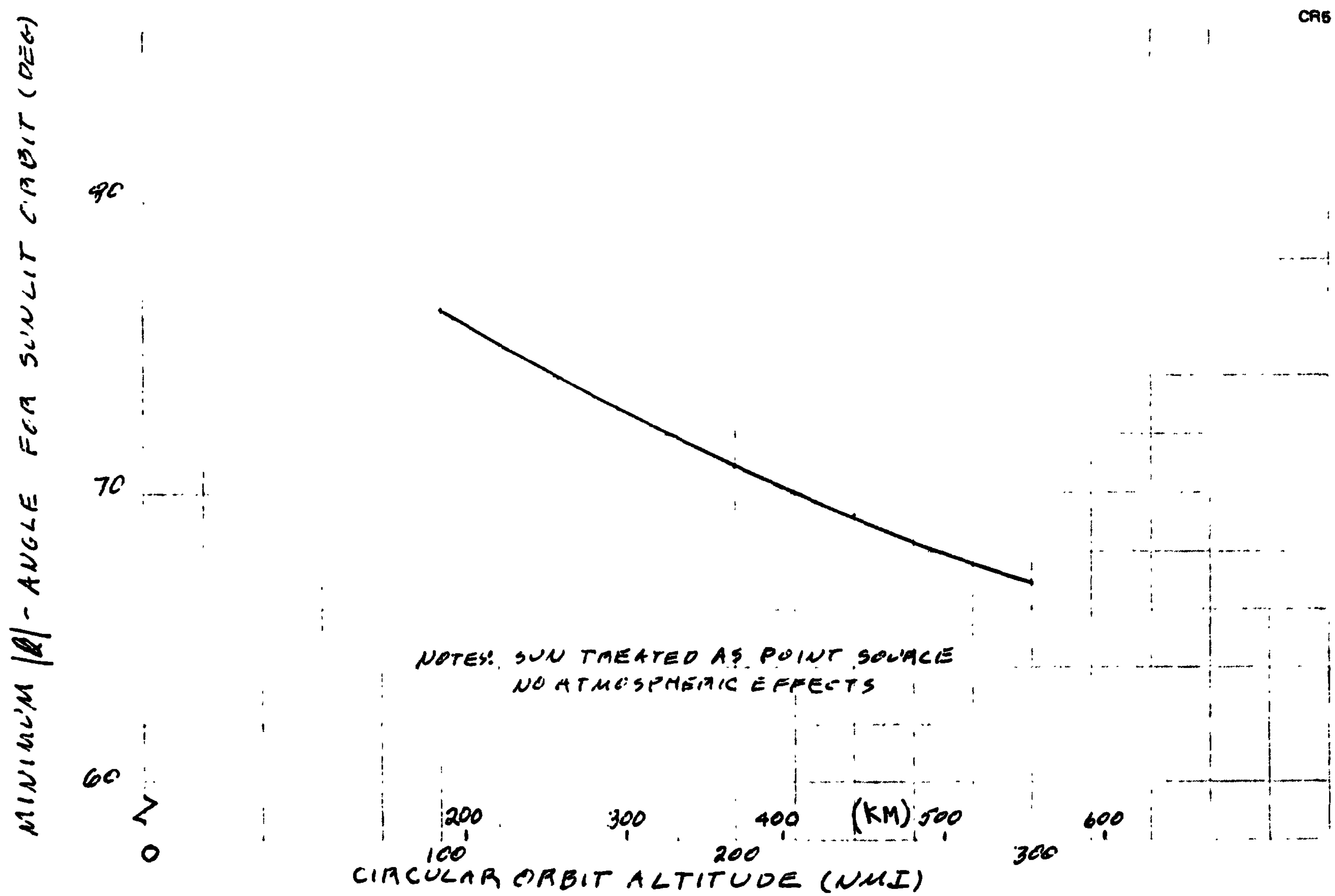

Figure 5-13. Effect of Orbit Altitude on β-Angle for Full Sunlit Orbit

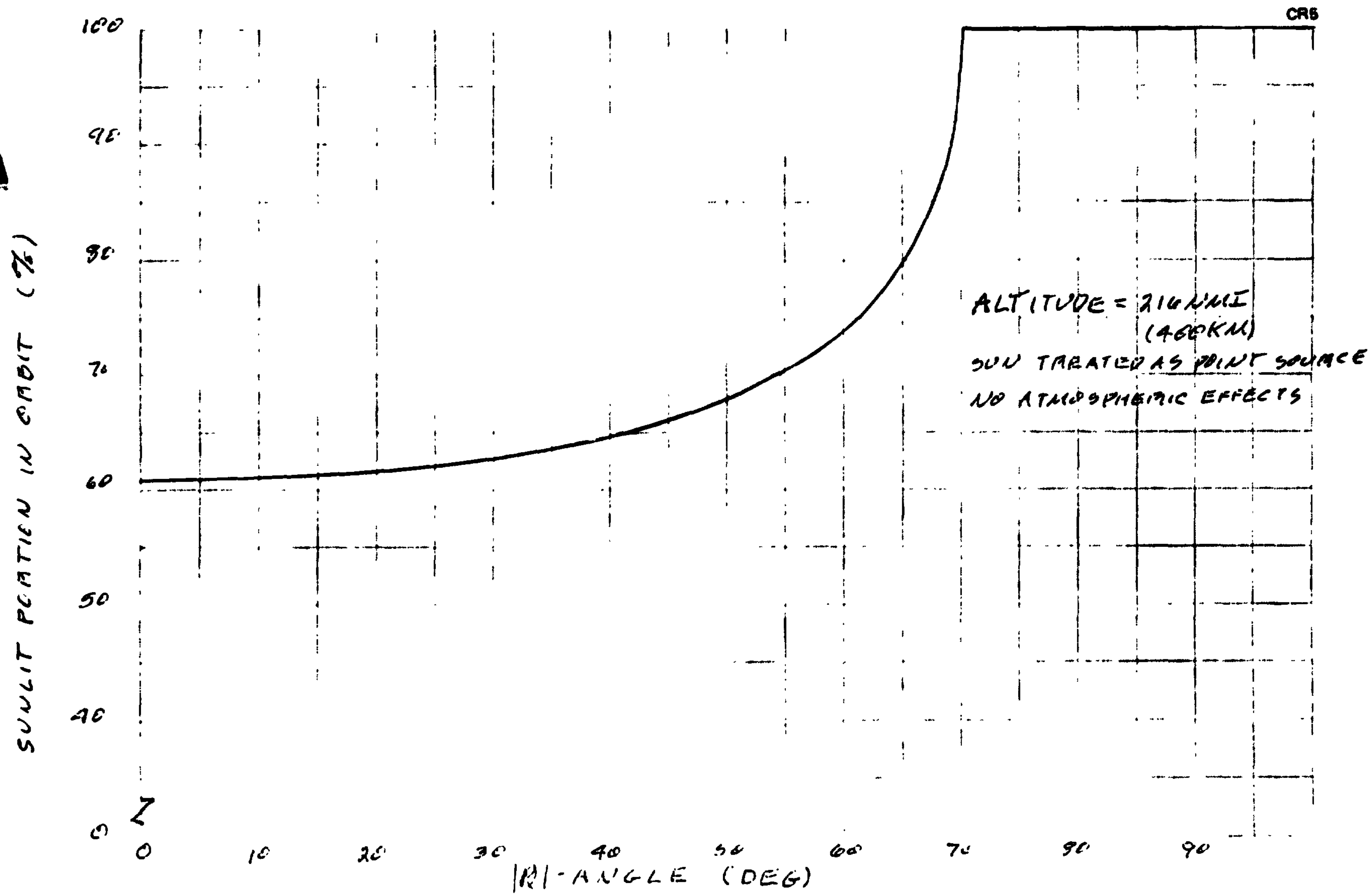

Figure 5-14. Portion in Sunlight

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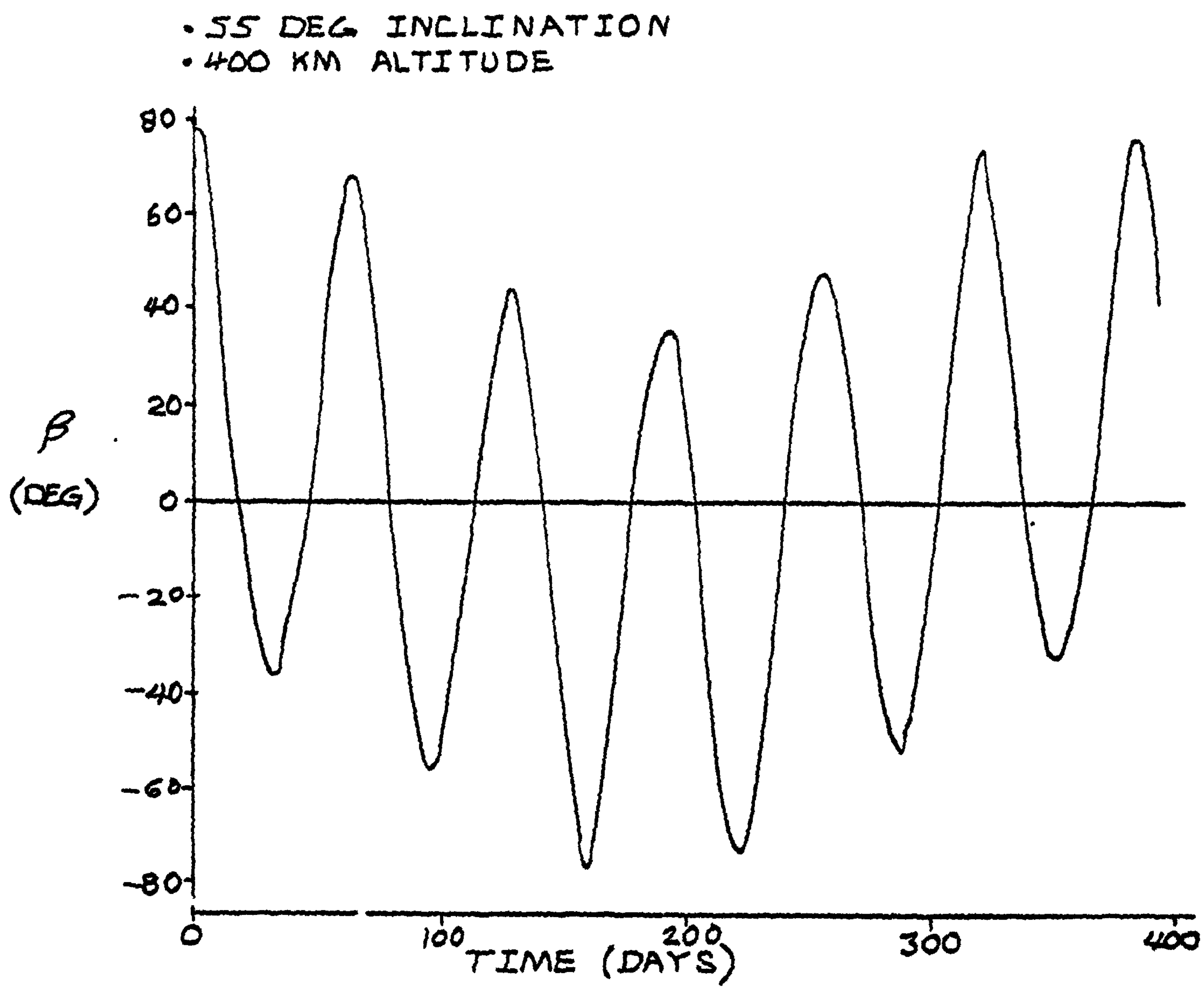

Figure 5-15. Typical β-Angle Time History

for a period of time greater than a year. The circular orbit altitude is 216 nmi (approximately 400 km) in which the orbit regression about the earth's pole is 4.665 deg/24 hours. The earth's orbit rate about the sun was assumed to be constant at 0.986 deg/24 hours. The initial condition is one in which the ascending node occurs at 6 pm (local time) at summer solstice. With only first order orbit dynamic effects included, the general trend appears to be a superposition of two near-sinusoids, one with a period of one year and the other with a period of approximately 64 days. The extremes ($\pm$78.5 deg) in β-angle are shown, indicating the nature of the containment of the angle. If the initial conditions change from those shown, the extremes will be the same but the phasing will be different. The maximum value for β-angle is the sum of the orbit inclination (55 deg) and the earth's axis tilt (23.5 deg).

The data of Figure 5-15 were analyzed to determine the function of time spent above a given magnitude of β-angle. The results of this are shown in Figure 5-16, indicating a nearly linear relationship from 100 percent at $\beta = 0$ deg to a zero likelihood at $|\beta| = 78.5$ deg. The 50 percent likelihood point occurs at $|\beta|$ = approximately 32 deg. Figure 5-15 indicates that the major portion of time is spent at lower β-angles. For a lower inclination orbit (say, $i = 28.5$ deg), the zero likelihood point would occur at the sum of the orbit inclination angle (28.5 deg) and the earth's axis tilt (23.5 deg), which is $|\beta| = 52$ deg.

5.3.3 Total of Vehicle-Shadowing and Earth-Shadowing Effects on Illumination Efficiency

The total illumination efficiency is the product of the earth-shadowing factor and the vehicle-shadowed factor (averaged during the sunlit period). The results for Orientation No. 2 (XPOP) are given in Figure 5-17 as a function of β-angle. As shown, it is clear that, even though vehicle-shadowing is very small at low β-angles, the earth-shadowing effect limits the illumination efficiency at low β-angles, and these conditions are drivers for the solar cell sizing. The limited data for Orientation No. 1 (YPOP) indicates the major vehicle-shadowing effect occurs at low β-angles, which makes it more critical to solar cell sizing than the other orientation. Although it is expected to be better at the lower likelikhood higher β-angles, the driving condition will be at the lower β-angles. Therefore, from the solar cell design standpoint, Orientation No. 2 (XPOP) is preferred.

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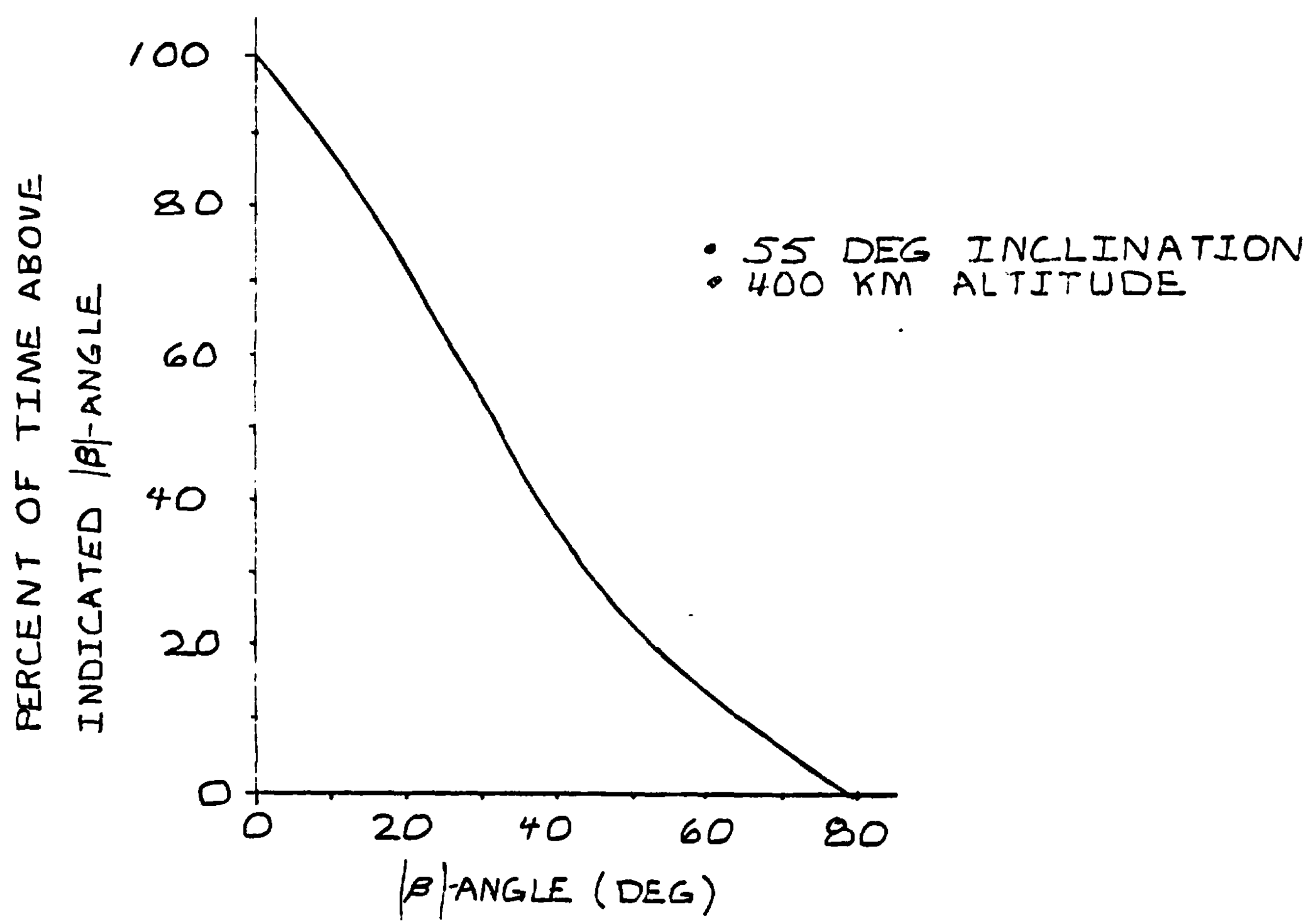

Figure 5-16. Probability of Being Above a Given β

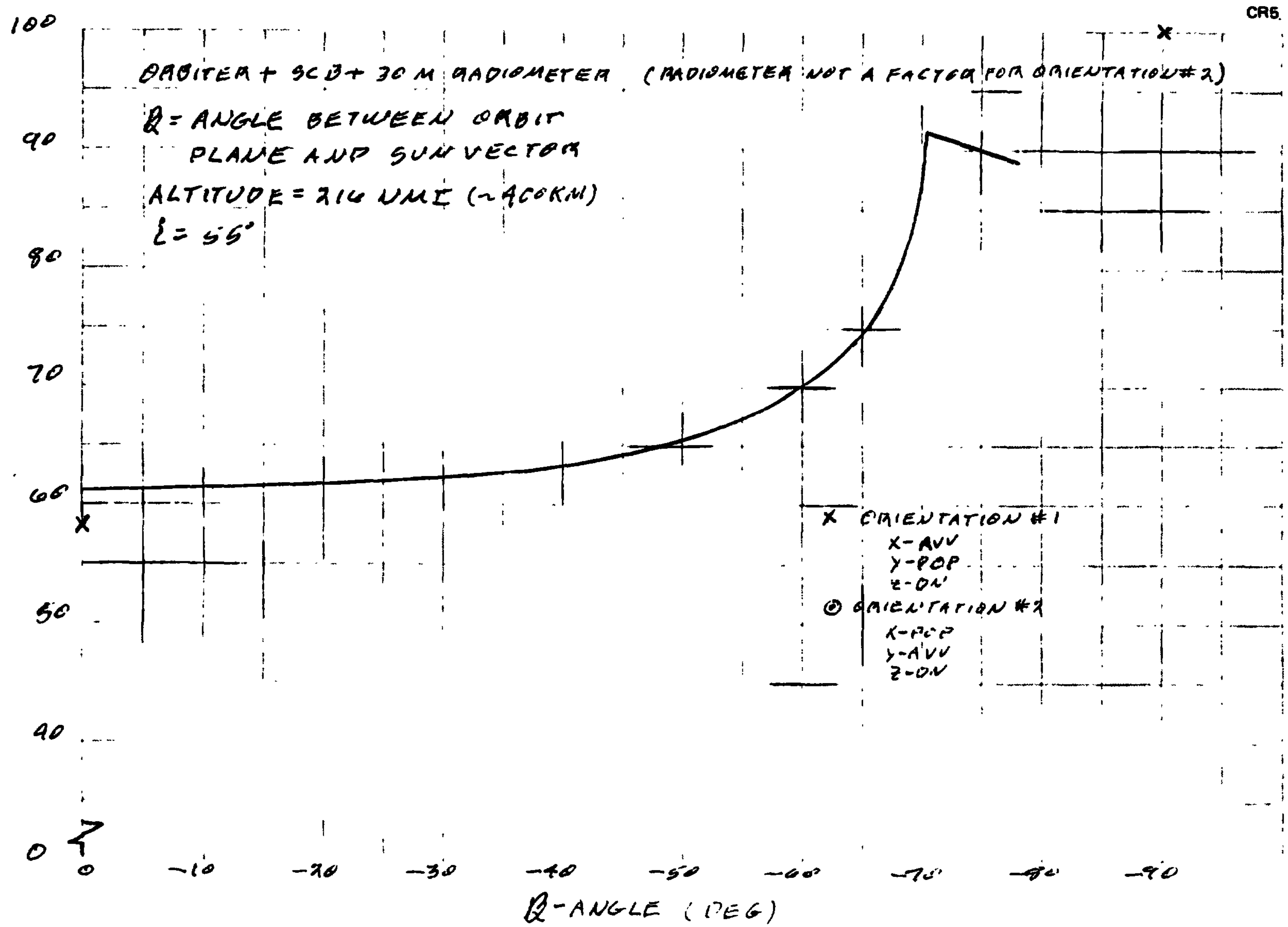

Figure 5-17. Solar Cell Total Illumination Efficiency Versus β-Angle

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Section 6
SUMMARY AND CONCLUSIONS

.e orientation study succeeded in providing considerable insight into various interacting technical aspects such as orbit mechanics, vehicle rigid body mechanics, aerodynamics, vehicle shape, and orientation. The adaptation of the highly flexible GVPAT computer program to orbit dynamics was achieved to provide a responsive tool for vehicle configuration studies. It models a dynamic atmosphere, an oblate earth, accepts inputs from a molecular flow aerodynamic program, accepts moment of inertia components, and determines the trajectory, force, moment, and impulse histories. It also has the capability to drop the present orientation constraint and permit a full six degree-of-freedom simulation with closed-loop attitude control. The solar cell shadowing program models the shape of the vehicle and displays solar cell shadowing by computer graphic techniques.

Four configurations, three β-angles, and three orientations were simulated, and the results have been analyzed. The conclusions drawn are numerous and are as follows:

- For minimizing orbit keeping and attitude control requirements over a lor time interval, an orientation with the principal axes of inertia (rather than the geometric axes) aligned to the center of the earth reduces the propellant usage from approximately 600 to 40 kg/30 days for the simplest configuration, and from approximately 6,000 to 170 kg/30 days for the most complex configuration.
- The effect of configuration size and complexity on propellant requirements is also considerable as seen in the above numbers. Propellant requirements for even the largest configuration are not severe, if the principal axis orientation is maintained. (No allowance for docking or other attitude transients has been included.)
- Generally, lower β-angles require more propellant than high β-angles; however, the likelihood of having high β-angles is not very great

(0.15 likelihood of $|\beta|$ in excess of 60 deg for a 55-deg inclination orbit). The reasons that the higher angles are less stressing are because of the lower solar cell gimballing requirements and the general avoidance of the atmospheric diurnal bulge associated with the dynamic atmosphere.

- Drag variations with orientations are not sever (3:1 for the simplest configuration and approximately 1:1 for the most complex), indicatint a high flexibility to allow a long-term minimum-moment orientation.
- Earth shadowing effects (maximum of 39 percent) appear to be more important than vehicle shadowing effects (maximum average of 12 percent on the vehicle solar panels.
- Lower β-angles result in more shadowing of the solar cells, and the XPOP orientation is preferred slightly over the YPOP orientation (by about 5 percent shadowing).

In short, the only major preference in orientation is for the principal inertia axis stabilization mode, and the associated orbit keeping and solar cell shadowing compromises do not appear to be very great. This should be tempered by the fact that consideration of radiator effectiveness relative to the sun and the earth have not been analyzed. The low β-angles appear to be the driving cases for both impulse sizing and solar cell shadowing.

REFERENCES

1. NASA document JSC 07700, Vol XIV, Space Shuttle System Payload Accommodations, Level II Program Definition and Requirements, Change No. 19, dated 12-2-76.

2. Hayes, W. D. and R. F. Probstein, Hypersonic Flow Theory, Academic Press, New York, 1959.

3. Hurlbut, F. C., Notes on Surface Interaction and Satellite Drag, Rand Report R-339, June 1959.

Part 2

ENVIRONMENTAL CONTROL/LIFE SUPPORT SYSTEMS ANALYSIS

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Section 1
INTRODUCTION AND SUMMARY

This part presents ECLSS design guidelines and criteria and typical ECLSS design descriptions used to evaluate Part 2 program options. The number of options considered in Part 2 were numerous but the appropriate associated ECLSS designs could be conveniently divided into a few distinct types.

The discussion which follows specifically addresses ECLSS designs for Shuttle-tended concepts and permanently manned concepts. Several levels of Shuttle dependency are considered in the Shuttle-tended mode. A single concept is presented for permanently manned vehicles. This single concept is believed to be near optimum from a cost standpoint for most LEO and GEO applications. This conclusion was reached upon review of past system studies and trades while taking into consideration current state of the art. Concepts were favored which are currently being developed because of the substantial nonrecurring cost savings to be realized. Much information comes from the current NASA/JSC-funded contract called, "Regenerative Life Support Evaluation (RLSE)." The goal of this contract is to develop a regenerative life support system for a Spacelab experiment. The concepts selected for the RLSE are nearly identical to the design used on the earlier Phase B Modular Space Station. Therefore, the design discussed in this part is basically the Phase B design, modified as indicated by the results of the RLSE program.

Also presented are the key ECLSS design guidelines and criteria which were extracted from NASA/JSC document JSC-11867 entitled, "Space Station Systems Analysis Study, Space Construction Base, Design Guidelines and Criteria."

Section 2
DESIGN GUIDELINES AND CRITERIA

Table 1 gives the significant design guidelines and criteria for the SSSAS at the program, system, and subsystem levels. Only guidelines which have a significant impact on the ECLSS design are listed. All information was taken from the updated version of the SSSAS Space Construction Base Design Guidelines and Criteria Document by NASA/JSC, dated 22 October 1976. The appropriate guideline paragraph number is noted in parentheses following the item.

Table 1 (Page 1 of 4)
GENERAL ECLSS REQUIREMENTS AND GUIDELINES

GENERAL

1. The space construction base (SCB) program includes the design, development, and operation of a TBD year orbital facility. The individual modules can be transported to and from LEO internal to the current space shuttle and to and from GEO by a COTV. If specific elements are not transportable by the current shuttle, they will be constructed on orbit, or in growth options, delivered to orbit by other launch vehicles. The space construction base will be capable of growth from an initial configuration capable of supporting up to TBD personnel in an Orbiter-tended or permanently manned mode to a growth configuration capable of supporting up to TBD crewmen. (1.01)

2. The SCB shall be capable of use in a LEO range of 0° to 90° inclination at an altitude between 370 km (200 nm) and 650 nm (350 nm) and at GEO with required design modifications. (1.03)

3. The initial SCB will be operational when it has the capability of being continuously manned. To be continuously manned, the SCB will have capability for environmental control and life support, electrical power, stabilization and control, guidance and navigation, communications, thermal control, and data management for a period of TBD days. (1.04)

4. Total cost of the program is a primary consideration. Primary emphasis is on minimum cost including recurring costs through the initial SCB operational period (FY85 to 1987). (1.07)

Table 1 (Page 2 of 4)

GENERAL ECLSS REQUIREMENTS AND GUIDELINES

5. The SCB shall be capable of accommodating a mixed male-female crew (5th to 95th percentile). (1.13)

MISSION OPERATIONS

1. The initial SCB shall have the capacity for independent operation with the full crew for a period of at least 90 days in LEO and TBD in GEO. (2.02)

2. At least 30 days of consumables, including those for habitability and mission objectives, shall be available beyond the scheduled resupply missions. (2.03)

3. For emergency conditions, the following capabilities shall be provided:

   a. Rescue by the Orbiter in 180 hours (LEO only).

   b. Rescue by a POTV within TBD hours (GEO only).

   c. Isolation of any module containing hazardous/toxic materials from the remainder of the SCB within TBD seconds.

   d. Rescue of up to TBD crewmen from an isolated module. (2.12)

CONFIGURATIONS

1. The initial SCB will be sized to accommodate at least TBD crewmen. Provisions for double occupancy will be provided in cases requiring exchange crew overlap periods that exceed the Orbiter's accommodations. The maximum crew overlap will be TBD crewmen for TBD days. (3.01)

2. A minimum of two separate pressurized habitable volumes with independent life support capability and habitability provisions will be provided at each manned stage of SCB buildup and operation. (3.03)

GENERAL SYSTEMS GUIDELINES

All of the systems that incorporate an automated fail/operational capability shall be designed to provide crew notification and data management system cognizance of the malfunction until the anomaly has been corrected. (5.02)

SYSTEM OPERATIONS

Solid wastes shall not be dumped in space (6.03)

ENVIRONMENTAL CONTROL LIFE SUPPORT (EVA/IVA, INTERNAL CONTAMINATION

1. The SCB and subsystems will be designed for an oxygen/nitrogen mixture at TBD total pressure and TBD partial pressure of O_2. (10.01)

Table 1 (Page 3 of 4)

GENERAL ECLSS REQUIREMENTS AND GUIDELINES

2. Carbon dioxide partial pressure will be maintained below 7.6mm Hg in all habitable areas. As a design goal, CO_2 partial pressure will be maintained below 3.8mm Hg in all habitable areas. In the event of a contingency situation, CO_2 partial pressure shall not exceed 15mm Hg. (10.02)

3. The capability for rapid depressurization and repressurization of the EVA/IVA airlock is required. This rate is not to exceed 1 psi/sec. Depressurization control should be possible from inside and outside the SCB as well as from inside the airlock. Repressurization control shall be possible from both inside the SCB and inside the airlock. Life support umbilical connectors shall be available outside the airlock. (10.03)

4. As a design goal, atmospheric leakage of each module should be less than 0.5 lb/day with a maximum of 5 lb/day for the SCB pressurized volume. (10.04)

5. Active thermal control coolant fluids in the pressurized volumes shall be water and air. Freon-21 shall be used outside the habitable volumes. (10.05)

6. Repressurization gas for at least one module shall be provided. As a goal, one repressurization of one pressurizable volume will be provided. (10.06)

7. Overboard gas venting is permitted. Vents shall be nonpropulsive. (10.07)

8. Crew-related consumables storage shall be sized for TBD days based on the 24-hour nominal man use rate. (10.08)

9. Particulate matter monitoring and filtration shall be provided in the ECLSS for removal of particles above TBD micron size. (10.09)

10. Radiation doses which affect personnel safety must be considered from all sources, including natural environment, onboard isotope and reactor sources, if any, microwave, and solar cosmic radiation. (10.10)

11. Module temperature shall be selectable $\pm 2°F$ between 65° and 80°F. (10.11)

12. Module humidity level shall be maintained between 40° and 60°F dew point temperature. (10.12)

13. The concentration of microbial count in the environment of each of the pressurized compartments containing crew quarters, process laboratories, or experimental facilities shall be monitored and controlled. (10.13)

Table 1 (Page 4 of 4)

GENERAL ECLSS REQUIREMENTS AND GUIDELINES

CREW SUPPORT SYSTEMS

1. Food composition shall be assumed to be 45% freeze dried, 30% frozen, 20% thermal stabilized, and 5% fresh foods. (19.05)

2. Provisi ns will be made to prevent transmission of objectionable and noxious odors emitted from food preparation and disposal areas to other areas of the SCB. (19.06)

Section 3
DESIGN DESCRIPTIONS

This section gives summaries of the ECLSS designs selected for (1) Shuttle-tended (L') configurations and (2) permanently manned (L) configurations. It initially describes what resources are available from the Shuttle, the capacity and capability, and the interfaces required between the Shuttle and SCB elements.

Then the L' concepts are grouped into three general categories: (1) initial capability, maximum Shuttle dependency, (2) intermediate Shuttle capability, and (3) growth capability, minimum Shuttle dependency. In all cases, Orbiter resources were used in the design if it was available, adequate and resulted in a workable interface.

Permanently manned concepts were assumed to fall into the category of closed water loop, semiclosed oxygen loop. The concept presented is a slight variation on the NAR Phase B design. Adequate water is available in the diet presented in the "Design Guidelines and Criteria for SSSAS" to make up for the oxygen loop being only semiclosed. In other words, sufficient water is resupplied as natural water content in the food to make up for oxygen lost overboard in the form of carbon dioxide.

3.1 SHUTTLE-TENDED CONCEPTS

3.1.1 General

The Shuttle-tended concept relies on a docked Orbiter to provide all or part of the available Orbiter resources for the ECLSS functions. The degree to which Orbiter resources were used depended upon the availability of the resource, the requirements for the resource, and the penalty for using the resource. These factors were treated primarily in a qualitative manner.

In the following paragraphs, these factors are discussed and the logic given for Shuttle resource use for SC bases of varying levels of capability.

3.1.2 Resources Available From the Orbiter

As a maximum, the Orbiter can supply all ECLSS resources for the Shuttle-tended SCB. The Orbiter is designed to provide for all crew ECLSS needs plus some additional support for payloads. Therefore, the Orbiter can provide all needs for the L' SCB concepts with support capability no greater than the Orbiter payload design values.

The minimum Orbiter support concept is essentially the non-Shuttle-tended or autonomous concept, where minimal support is obtained from the Orbiter.

Basic resources/available, capability or capacity, and the physical interfaces with the Orbiter are presented in Table 2. These are normally made available to payloads and represents the basic ECLSS capacity of the Orbiter to support the normal 4-man crew for 7 days. Orbiter capacity can be increased to 7 men for 30 days with the addition of appropriate kits. The payload interfaces described in Table 2 were designed for a payload located in the bay, namely Spacelab. The L' SCB will interface at the docking port of the docking adapter. Therefore, the ECLSS interfaces from the Orbiter are not located most conveniently for the SCB.

3.1.2.1 Atmosphere Pressure and Composition Control

Oxygen partial pressure and total pressure and total pressure, by the addition of oxygen and nitrogen, are maintained within the Orbiter cabin by Orbiter systems. The design has sufficient capacity to also maintain pressure and composition of the atmosphere of a payload, subject to the flow-rate limitations of the oxygen and nitrogen supply systems.

Since the oxygen pressure and total pressure are sensed in the Orbiter, sufficient flow rate must exist between the Orbiter and habitable volumes of the payload to eliminate excessive atmosphere composition gradients. Oxygen partial pressure between the Orbiter and SCB due to a crew in the SCB is shown in Figure 1. The results show that even with a crew of 6 men,

Table 2

ECS RESOURCES NORMALLY AVAILABLE FOR SCB SUPPORT

Resource	Capability/Capacity	Interface
Atmosphere Pressure and Composition Control		
O_2 pressure control	0.217 atmos (3.2 ±0.25 psi)	Via Orbiter atmosphere (circulated)
Total pressure control	1 atmos (14.7) Nominal	Via Orbiter atmosphere
Oxygen Supply	25.4 Kg (56 lb) from each ECS cryo kit max flow rate, 6.4 Kg/hr (14 lb/hr)	1.3 cm (1/2 in) line at payload heat exchanger panel
Atmosphere Revitalization		
CO_2 control	up to 25 men	22.7 lps (48 cfm) at tunnel and adaptor
Humidity control	up to 5 men	22.7 lps (48 cfm) at tunnel and adaptor
Cooling available	up to 6 men or 520 Watts	22.7 lps (48 cfm) at tunnel and adaptor
Particulate filtration	300 micron (22.7 lps) (48 cfm)	22.7 lps (48 cfm) at tunnel and adaptor
Orbiter and containment control	Orbiter requirements (7 day)	22.7 lps (48 cfm) at tunnel and adaptor
Active Thermal Control Cooling		
On orbit at payload Hx	5.9 to 6.3 kW without radiator kit 8.1 to 8.5 kW with radiator kit	Coolant line at payload heat exchanger Coolant line at payload heat exchanger
On orbit at aft flight deck	0.75 to 0.35 kW*	Air cooling, Orbiter system
On orbit peaks at aft flight deck	1.0 kW for 15 min each 3 hours	Coolant line at payload heat exchanger
Orbiter flight phase at payload Hx	1.52 kW	Coolant line at payload heat exchanger
Orbiter flight phases, aft flight deck	0.35 kW ave., 0.42 kW peak for 2 min	Air cooling, Orbiter system
Potable Water Supply		
Storage capability	2 tanks at 75 Kg (165 lb) each	Supply line in Orbiter mid deck
Water availability	0.38 Kg/kW hr (0.84 lb/kW hr) less supplemental cooling requirements.	Supply line in Orbiter mid deck

* Minimum aft deck cooling capacity corresponds to maximum cooling at payload heat exchanger

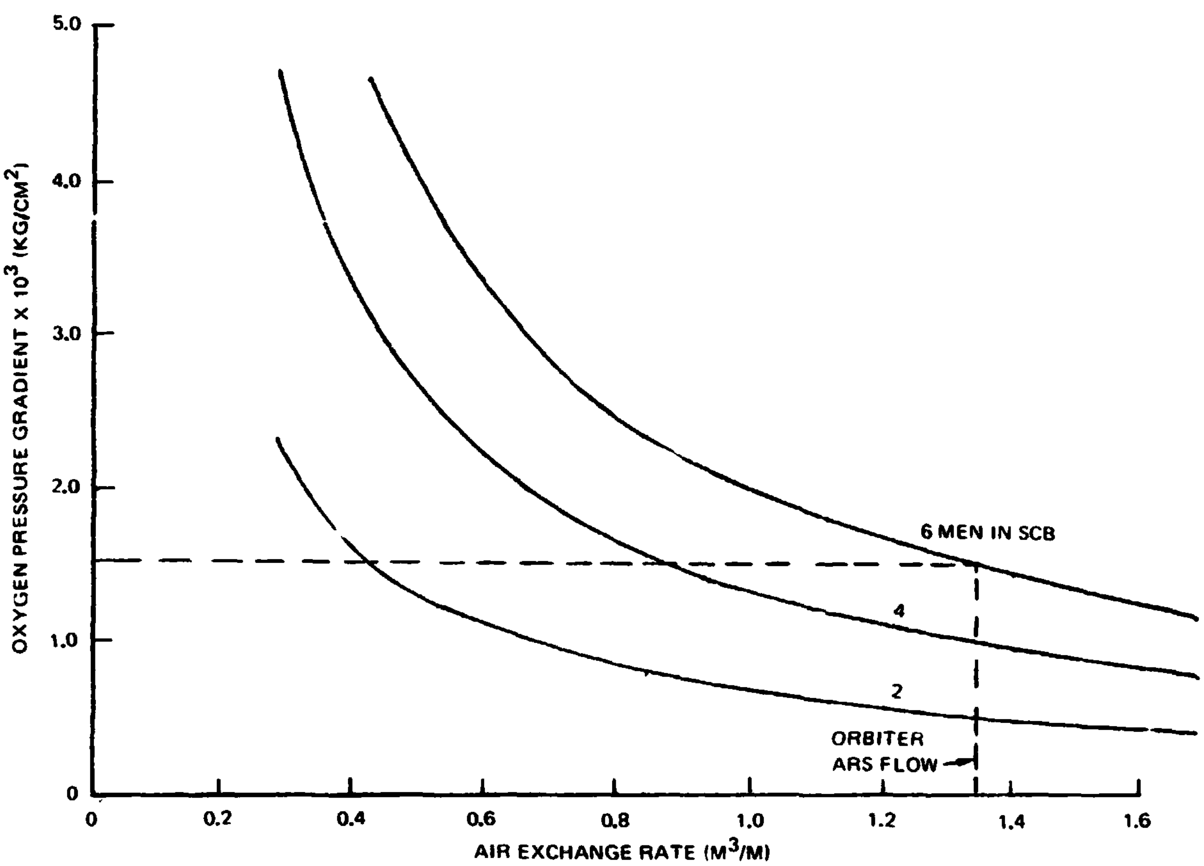

Figure 1. Oxygen Pressure Gradients Between Orbiter and SCB When Orbiter System is Controlling

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a small O_2 gradient will occur at the Orbiter Atmosphere Revitalization System (ARS) air flow rate of 1.36 m^3/min (48 cfm). The value of 0.0015 Kg/cm^2 (0.022 psi) is only about 4% of the tolerance of the O_2 control system, and is not expected to be measurable or have physiological effects on the crew.

As long as a reasonable flow path exists between Orbiter and SCB, the total pressure will be essentially the same in both compartments. An open hatch or duct for ARS interchange represents a sufficiently large flow path.

3.1.2.2 Oxygen and Nitrogen Supply

Up to 25.45 Kg (56 lb) of O_2 are available to the payload from each cryo kit added for payload use. This amount represents about 30 man-days of oxygen for metabolic use. As the crew size and mission duration increases, the electrical energy requirements and the corresponding power cryo kits will be increased. The rate of power increase is estimated to be about 1 kW average power for each additional crewman for 30 days and the 25.45 Kg (56 lb) of O_2 in the kit will provide the metabolic O_2 for the one additional crewman. Additional oxygen must also be provided for leakage makeup, repressurization if required, and airlock usage above those chargeable to the Orbiter (three two-man EVA's, 6-hour duration).

Nitrogen supply is not a planned resource to be supplied to the payload except for EVA support, but can be implemented by the addition of nitrogen storage tanks. The weight of additional tanks and associated mounting provisions are chargeable to the payload.

The baseline Orbiter design provides 44 man-days of metabolic oxygen, of which 16 man-days is for contingency use. Cabin leakage and EVA makeup are also provided. All requirements above this are chargeable to the SCB including oxygen, tankage, and associated mounting equipment.

Location of the oxygen supply interface is via a payload kit which provides a 0.635 cm (1/4-in) line connection at the payload heat exchanger panel.

3.1.2.3 Atmosphere Revitalization

The Orbiter is designed to provide 1.36 m^3/min (48 cfm) of revitalized air for payload use. This resource would be useful in reducing the ECS equipment needs for attached habitable volumes for the Shuttle-tended SCB. The 1.36 m^3/min (48 cfm) has the capability of providing CO_2 control, humidity control, particulate filtration, odor and contamination control, and sensible cooling. Availability of these resources are limited by the air flow rate of 1.36 m^3/min (48 cfm), the outlet conditions from the ARS and allowable return conditions. Limitations are imposed on return air to prevent overtaxing of the ARS.

Table 2 addresses the capacity of the ARS supply air for an L' SCB in terms of crewmen supported at nominal metabolic rates (164 Watts/man). The table data shows that the Orbiter ARS has the capacity to support up to a 5-man crew, limited primarily in the areas of humidity control and sensible cooling. Cooling is particulary limited because the supply of air, at most, can only provide crew cooling, and equipment cooling requirements in an attached habitable module would be expected to be orders of magnitude greater. Equipment cooling is expected to amount to several kilowatts. The ARS supply air cannot provide this but the Orbiter provides a generous active thermal control capability; this will be discussed in the next section.

The resources for particulate filtration are somewhat limited because of the low air flow and relatively coarse 300-micron filtration. This may not be adequate for some habitable module requirements. Determination of adequacy will be determined when detailed equipment requirements/particle generation rates are known.

Odor and contamination control in the Orbiter is based on a relatively short seven-day mission and without consideration of payloads generating substantial amounts of contaminants; the odor and contamination control capability provided by the Orbiter ARS is expected to be marginal for longer-duration missions with some payloads.

Use of the ARS air flow involves the addition of equipment and expendables whose weight is chargeable to the payloads. Specifically, fixed weight

chargeable to the SCB includes the duct kit, storage provisions for LIOH canisters, and waste water tanks including tubing and mounting provisions. Weight-chargeable expendables consist of LIOH canisters beyond the 22 normally provided, of which 14 are for normal use and 8 are for contingency use. Each canister provides two man-days of CO_2 removal and odor and contamination control. Stowage provisions beyond 29 canisters are SCB-chargeable.

Humidity condensate and urine are stored in three tanks, each of 75 Kg (165-lb) capacity in the baseline Orbiter design. This represents 42 man-days normal capacity plus 16 man-days contingency mode capacity. Any capacity required above this amount by the SCB will be chargeable to the SCB and will consist of additional tanks plus associated tubing.

With the ARS duct kit installed, the ARS duct interface is at Station X_o660, which is internal to the pressurized volume of the tunnel and adapter.

3.1.2.4 Active Thermal Control

In addition to the 520W cooling available via the ARS air flow, the Orbiter provides additional cooling to the payload via a coolant passage in the payload heat exchanger. Additional air cooling is available for payload equipment located in the aft flight deck. Table 2 shows the cooling which is available for the various mission phases. The cooling available at the payload heat exchanger during on-orbit operation depends on the installation of a radiator kit which increases radiator area and coolant flow rate. This kit is payload chargeable and increases the cooling available to the payload by 2.2 kW.

Limitations also exist on SCB coolant loop inlet and exit temperatures at the payload heat exchanger. SCB supply temperature cannot be below 1.67° - 3.33°C (35° - 38°F) (depending on operational mode) because these are the Freon temperatures on the Orbiter side of the payload heat exchanger. Maximum SCB loop return temperature cannot exceed 54.4°C (130°F) and the flow must be modulated to not exceed the maximum allowable heat rejection loads listed in Table 2. Depending upon the SCB return temperature, coolant flow

rate, and Orbiter side coolant conditions, the SCB supply temperature can be determined by performance data given in STS Payload Accommodations. JSC-07700, Vol XIV. Either Freon 21 or water are acceptable fluids for the payload heat exchanger, which is designed with redundant fluid passages.

Cooling capability for the SCB is much less during prelaunch, ascent, descent, and landing because the radiator is not deployed and Orbiter cooling is by ground equipment, ammonia boiler, or flash evaporator. During these mission phases, 1.52-kW cooling is available at the payload heat exchanger and 0.35-kW cooling is available in the aft flight deck. A peak aft flight deck load of 0.42 kW is available for a 2-min period.

During ascent, when the Orbiter has no heat rejection capability, the Orbiter side payload heat exchanger temperature can reach 26.7°C (80°F). This condition can last for 2 min after liftoff until an altitude of 140,000 ft is reached, whereupon the flash evaporator becomes operational.

The payload heat exchanger is located at the forward bulkhead of the payload bay in an unpressurized area. The payload side of the heat exchanger is compatible with being serviced through interconnecting lines prior to payload installation. This "wet-mate" capability will require that interconnecting lines contain service fittings or quick disconnects. SCB coolant cannot exceed a pressure of 200 psia.

3.1.2.5 Potable Water Supply

Many Shuttle-tended concepts rely entirely or largely on the Orbiter fuel cells for electrical power. The water produced by the fuel cells is available for crew use or for supplemental cooling in the flash evaporator. The water production rate is about 0.84 lb per kW-hr of electrical energy produced. Two potable water tanks are provided in the baseline Orbiter; each holds 75 Kg (165 lb) of water.

During the normal 7-day Shuttle mission, water is generated at about 7.27 Kg/hr (16 lb/hr) for a typical Orbiter power level of 19.5 kW total, 5.5 kW to the payload.

Missions of longer duration are expected to operate at a lower power level and precise values are subject to detailed analyses. However, based on the normal Orbiter crew water use rate of 4.09 Kg/man-day (9 lb/man-day), a fuel cell power level of 0.45 kW/man or 3.15 kW/7-man crew will produce all crew water requirements. This power level would not produce any water for supplemental cooling which may be required for certain geometrical configurations of docked Orbiter-SCB attitudes and orbits. However, since relatively low fuel cell power levels are expected in the L' SCB concepts, supplemental cooling may not be required. However, if the power level falls below the 0.45 kW/man level, some means of water resupply or water recovery may be required.

Location of the potable water supply is in the mid-deck region of the Orbiter. This location is compatible with the crew habitable area in the Orbiter but not in the SCB.

Adequacy of the potable water tanks depends upon the cyclic production and use profile. Excess water must be expended through the flash evaportor periodically when the tanks are nearly full or when supplemental cooling is required. It is felt that in the L' concepts which rely heavily on the Orbiter support, the existing waste water tanks will be adequate for most cases. This assumes that little supplemental cooling is required and that no experiments or activity is occurring which precludes periodic operation of the flash evaporator.

3.1.3 System Concepts for Shuttle-Tended Concepts

Synthesis of ECLS system concepts depends largely on other concepts for SCB systems, operations, and objective elements. The concepts for ECLSS presented were chosen relatively independent of these factors, based on generally increasing capability for (1) time duration, (2) resources available for objective elements, and (3) crew size. Three distinct levels of capability are present which represent initial capability, intermediate capability, and growth capability. The "L" SCB, which is not Shuttle-tended would be the logical next step beyond the growth version.

3.1.3.1 Initial Capability Shuttle-Tended SCB

This concept, shown in Figure 2, uses all Orbiter resources, the SCB provides no ECLSS services by itself except for ducting and a fan to draw the 1.36 m^3/min (48 cfm) of air from the Orbiter ARS. A single presurized SCB module can be accommodated with this concept where the sensible heat loads are either very small or are accommodated by passive means.

Interfaces are a minimum, consisting only of a duct for the ARS air. All habitability functions and maintenance of atmosphere are performed within the Orbiter. Therefore, the hatch between the SCB and Orbiter must remain open to maintain a habitable atmosphere. Depending upon the size and occupancy of the SCB, a ventilation fan might be required in the habitable SCB volume.

Some means is required in the SCB module if it is to be returned to earth after it has been depressurized. A port or hatch must be opened during reentry to prevent negative pressure collapse of the pressure shell.

When the Orbiter is not attached to the SCB, pressure decay will occur within the SCB at a rate dependent upon the structural leak rate. No means of active thermal control is present, so passive thermal control methods are required to prevent equipment and structural temperature from exceeding limits.

3.1.3.2 Intermediate Capability Shuttle-Tended SCB

Figure 3 depicts an ECLS concept with intermediate performance. This concept is identical with the one designed for initial capability except that the Orbiter TCS is used for actively cooling the atmosphere and equipment within the SCB. This addition substantially increases performance but complicates the Orbiter-SCB interface somewhat because of the need to make a "wet" hookup on orbit. The intermediate concept increases the cooling capability within the SCB to from 5.9 to 8.5 kW, depending upon the cooling in the Orbiter aft flight deck and the installed Orbiter radiator system (kit increases capability).

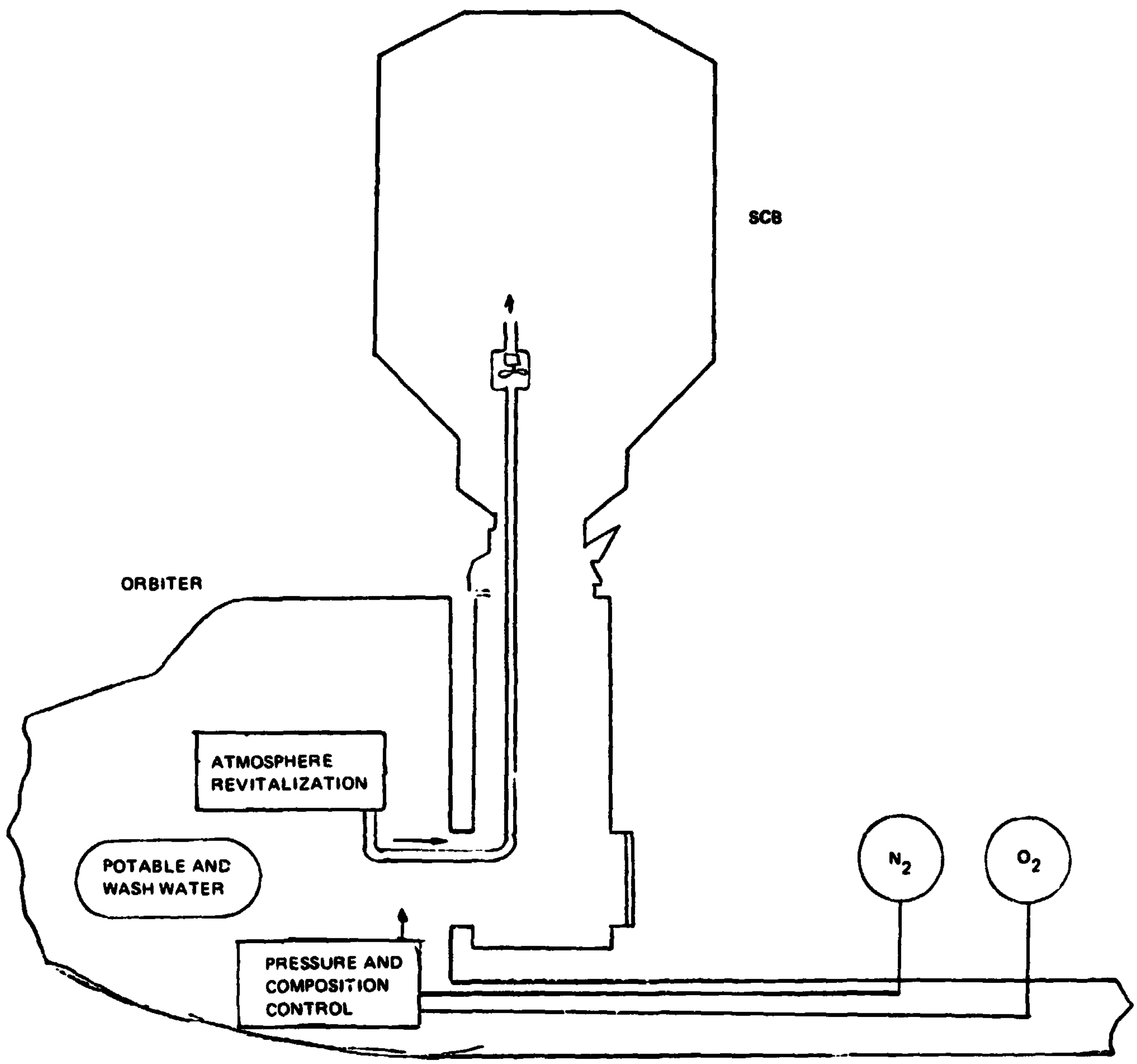

Figure 2. Initial Capability Shuttle-Tended ECLSS

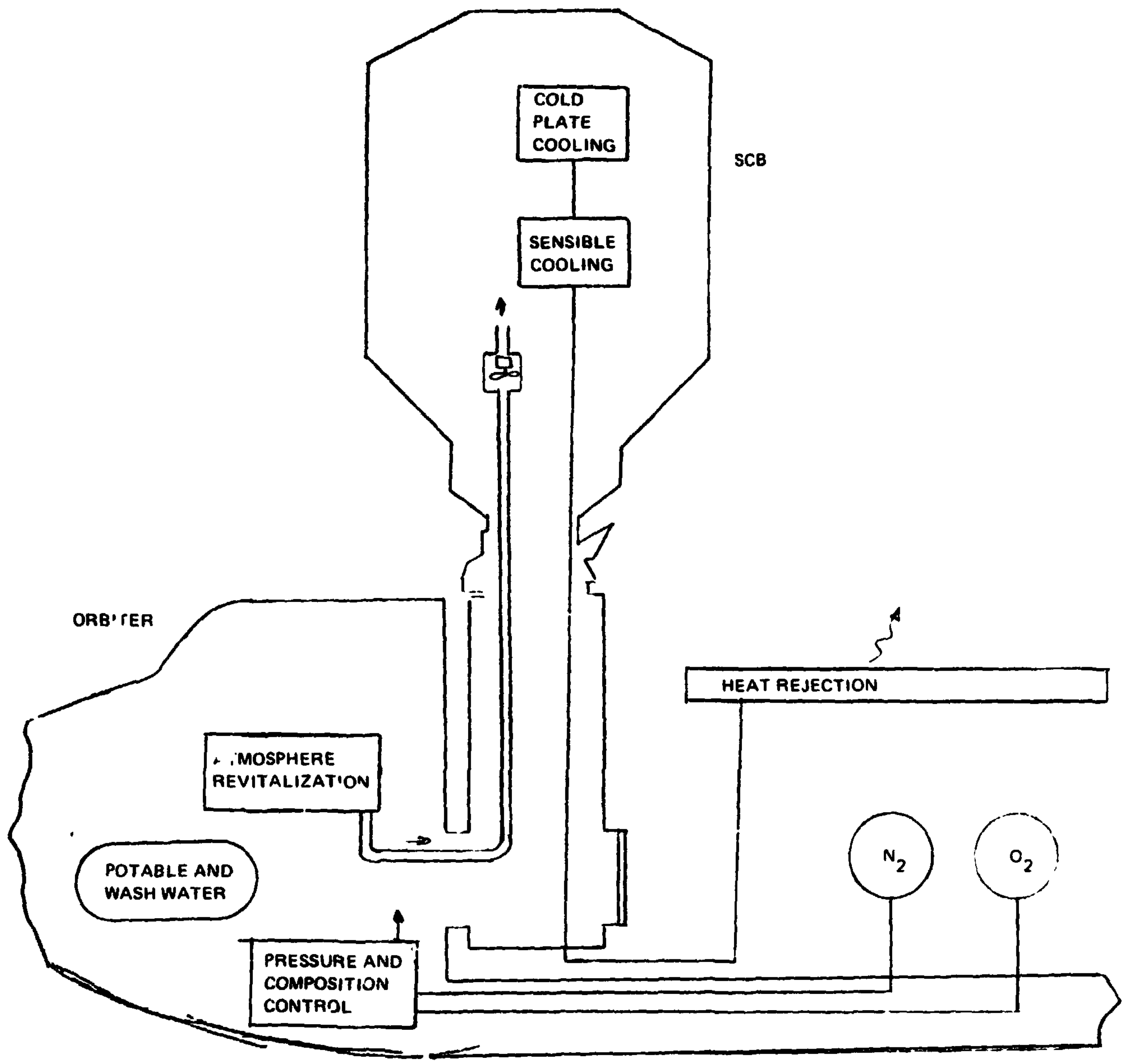

Figure 3. Intermediate Capability Shuttle-Tended ECLSS

Normally, the intermediate concept will not be limited by the heat-rejection capability. This is because the Orbiter heat-rejection system can reject all the heat normally produced by the fuel cells plus a 7-man crew. Shuttle-tended missions of longer duration will tend to use lower average power levels because of larger fuel cell reactant requirements for extended times.

A major drawback of the intermediate capability concept is that no active thermal control or atmosphere maintenance capability exists when the orbiter is not attached. Atmosphere maintenance can easily be added with a simple assembly consisting of a high-pressure tank of air and total pressure regulator for leakage makeup.

3.1.3.3 Growth Capability Shuttle-Tended SCB

Several assemblies may be added to the intermediate capability concept to accommodate larger crews for longer durations where more capability is desired of the SCB. Figure 4 shows this concept, which has assemblies added for total pressure and composition control, wash water recovery, and heat-rejection capability. This concept relies on the Orbiter for atmosphere revitalization, potable water supply, and supplemental heat rejection. The rationale for this selection of Orbiter versus SCB provided functions is discussed below.

The growth version L' SCB design is assumed to have the following characteristics:

- Orbiter powered down.
- SCB has its own electrical power system.
- Most habitability functions in Orbiter.
- Long-duration Shuttle-tended mode.
- Thermal control and atmosphere maintenance when SCB is not Shuttle-tended.

Total pressure and composition control is provided in the SCB to allow atmosphere maintenance during unattended periods and also reduces the interface between the Orbiter and SCB. This provision also enables repressurization of the SCB within reasonable time periods and supports extensive airlock repressurization for EVA.

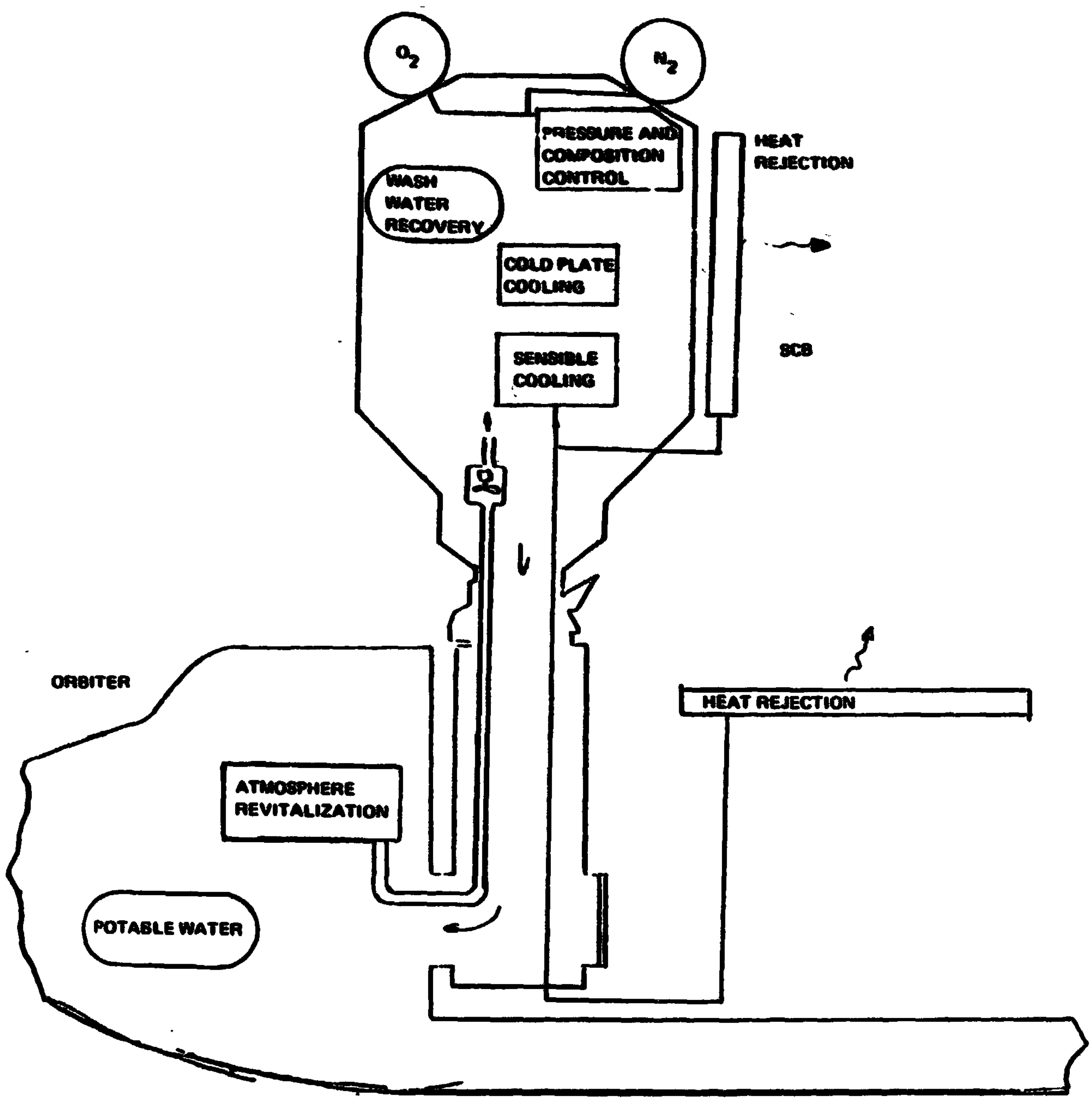

Figure 4. Growth Capability Shuttle-Tended ECLSS

Wash water recovery within the SCB enables a crew hygiene concept, such as full body shower, to be used, which is desirable for extended missions. This provision is indicated because of the low assumed fuel cell power usage with the attendant low production of water. It is assumed that sufficient fuel cell water will be produced for crew potable water needs; this amounts to a power level of about 0.3 kW/crewman. This power level is consistent with anticipated power levels with the fuel cell in idling mode. The potable water requirement of 2.73 kg/man-day (6 lb/man-day) would be reduced if a wet diet was used which did not contain primarily dried foods as Orbiter uses. Adaption of a "wet" diet, containing food with natural water content, would reduce the lower limit of the fuel cell power required to produce adequate potable water.

Heat-rejection capability has been added to the SCB elements to reject the larger amounts of heat which will be produced in a growth-version SCB. Additionally, the active thermal control system is needed to maintain thermal control when the Shuttle is not attached.

3.2 PERMANENTLY MANNED CONCEPTS

A large number of permanently manned Space Station concepts were examined in Part 2 of the study. An ECLSS design was selected which was applicable to the entire range of concepts, which included both LEO and GEO applications. This ECLSS concept has traded favorably in recent Space Station studies, in particular, the Modular Space Station Study, which had requirements and penalty factors similar to those of the systems analysis study. Therefore, the basic ECLSS design resulting from this previous study was chosen as baseline for the permanently manned concepts. The design was modified only as required to meet requirements unique to the SSSAS concepts and where updated data was available. The RLSE contract funded by NASA/JSC was the focal point for most recent design data.

The chosen ECLSS concept features a closed water loop and a semiclosed oxygen loop. Table 3 lists the functions and chosen concepts for the design. Extravehicular activity support, waste management, hygiene, food, food preparation, and related crew systems equipment are covered in another part of this book.

Table 3

FUNCTIONS AND BASELINE ECLSS CONCEPTS FOR PERMANENTLY MANNED SPACE STATION

Function	Concept
Atmosphere supply and control	
• Makeup and repressurization O_2 and N_2	• High-pressure gas storage
• Pressure control	• 2 Gas control assembly and dump and relief valves
• Airlock pressure control	• Expendable initially, and pump down for growth
Atmosphere reconditioning	
• Humidity control	• Condenser
• Trace contaminant control	• Charcoal and catalytic oxidizer
• CO_2 removal	• Electrochemical depolarized concentrator
• Trace contaminant monitor	• Mass spectrometer/gas chromatograph
• Air temperature control	• Zone-sensible heat exchangers
• Oxygen generation	• Water electrolysis
• Oxygen recovery	• Sabatier reactor
Water recovery	
• Urine water recovery	• Vapor compression distillation
• Wash water recovery	• Hyperfiltration
• Potable water treatment	• Multifiltration
• Water storage	• Bladder tanks
• Water sterilization	• Iodine dispenser
Thermal control	
• Active internal liquid cooling	• Water loop/pumps
• Heat rejection	• Freon 21 loop/pumps/external radiator
• Coolant loop interchange	• Heat exchanger and bypass controls
• Liquid cooling	• Cold plates
• Passive thermal control	• Superinsulation, low-conductivity materials, and thermal coatings
Emergency ECLSS	
• 180-hr emergency ECLSS	• Self-contained expendable unit (pallet)

A mass balance for the ECLSS is shown in Figure 5 and is based on the following key performance assumptions:

- Overboard leakage, 2.27 Kg/day (5 lb/day).
- Oxygen pressure, 0.225 Kg/cm^2 (3.2 psia) (nominal).
- Cabin dew point temperature, 40.2°C (58°F) (maximum).
- CO_2 partial pressure, 3.8 mm Hg.
- Urinal flush, 0.577 Kg/man-day (1.27 lb/man-day).
- Food water, 0.436 Kg/man-day (0.96 lb/man-day).
- Water intake (food preparation and drink), 3.83 Kg/man-day (6.9 lb/man-day).
- Urine output, 2 Kg/man-day (4.4 lb/man-day).
- CO_2 output, 1 Kg/man-day (2.2 lb/man-day).
- O_2 consumption, 0.836 Kg/man-day (1.84 lb/man-day).
- Crew latent output, 174 Btu/man-hour.
- Fecal water, 0.09 Kg/man-day (0.2 lb/man-day).
- Electrochemical depolarizer cell O_2 consumption, 0.45 Kg/man-day (1 lb/man-day).
- Sabatier reactor efficiency, 95%.
- Sabatier reactor condenser temperature, 27.2°C (45°F).
- Wash water rejection, 10%.
- Vapor compression distillation reject, at 50% solids.
- Multifiltration efficiency, 99%.
- Shower water, 3.43 Kg/man-day (7.55 lb/man-day).
- Water vapor loss from shower, 0.023 Kg/man-day (0.05 lb/man-day).

These assumptions and values of performance are from the RLSE program documentation where available; Modular Space Station data was used when RLSE data was not applicable or complete.

Based on these assumptions and performance data, the mass balance for the permanently manned SCB shows an excess of 0.027 Kg (0.06 lb) of water per day. This results largely from the food diet, which has only 45% freeze-dried foods; more than half the diet has natural water content. Additionally, 3.57 Kg/day (7.85 lb/day) of water is generated in the CO_2 removal system (electrochemical depolarized concentrator). These two sources of water make it unnecessary to recover all of the oxygen from the CO_2 in the Sabatier reactor. Material inputs to the SCB are 3.05 Kg/day (6.72 lb/day) of water contained in the food and 1.68 Kg (3.7 lb) per day of nitrogen. The Sabatier reactor

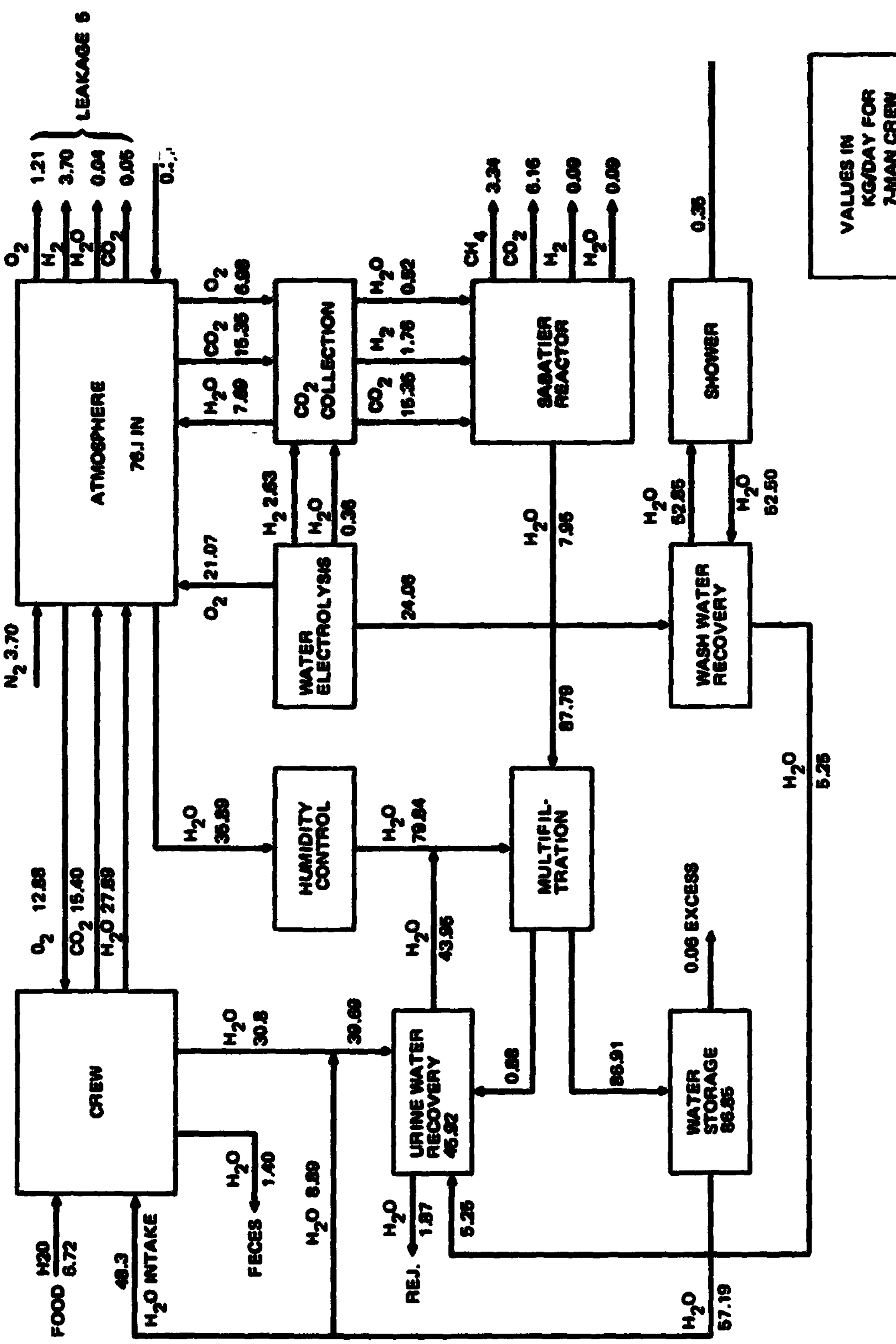

Figure 5. SCB Mass Balance (7-Man Permanently Manned)

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provides 4.4 Kg/day (9.68 lb/day) of gases, mostly methane and carbon dioxide, which could be used as propellant in a reaction control system. The mass balance is highly sensitive to water and oxygen recovery unit efficiencies, food water content, and overboard leakage.

Figure 5 shows the major interfaces between ECLSS assemblies.

3.2.1 Atmosphere Supply and Control

This assembly group stores atmosphere makeup and repressurization gases, and supplies them as needed to maintain the atmosphere within specified limits. It additionally protects against overpressure and excessive negative pressure, and allows manually dumping of modules in the event of fire or contamination. The assembly group also provides for airlock pump down, depressurization and repressurization.

Atmospheric stores in the form of oxygen and nitrogen are stored as high-pressure gases in the baseline design. This method has the advantage of low initial cost, and the design is independent of use rate. The main competitor with high-pressure gas storage is cryogenic storage, which is a high-technology method resulting in a lower storage weight (tank) penalty. Long-term storage is possible with cryogenics; however, some minimum use rate is necessary, corresponding to boiloff caused by heat leaks into the tank. Cryogenics have the disadvantage of being more costly initially and requiring more time to repressurize large volumes. Although high-pressure stores are baselined, cryogenic storage is a strong candidate for GEO missions because of the low storage penalty.

Oxygen and nitrogen are supplied to the SCB via an assembly of pressure-reduction valves, pressure regulators, and solenoid valves. Oxygen partial pressure and total pressure are sensed, and this information is used by a controller and pressure regulator to maintain oxygen partial pressure and total pressure.

Overpressure protection is provided by a relief valve which relieves excessive module pressure in the event of excessive O_2 or N_2 being admitted to the cabin,

fire, or activation of the fire-suppressant system. The pressure-relief function may also be used during launch to allow pressure relief if an on-orbit pressure lower than 1 atmosphere is desired. Negative pressure relief is required if a module with a pressure lower than 1 atmosphere is returned to earth.

Early SCB designs are expected to use an expendable airlock pressurization system where the airlock atmosphere is merely dumped prior to EVA. On-board atmosphere storage is then used to repressurize the module upon termination of EVA. This approach requires large O_2 and N_2 resupply, and for frequent EVA, airlock pumpdown trades favorably. Prior to EVA, the airlock atmosphere is pumped to an accumulator or into the cabin volume if cabin volume is sufficiently large to prevent excessive pressure variations. After EVA termination, the airlock is repressurized from the cabin or accumulator. Since it is impractical to remove all airlock air by pumping, a small amount must be dumped to space after pumpdown and then made up from on board stores.

3.2.2 Atmosphere Reconditioning

Atmosphere reconditioning refers to the assemblies which process cabin air to remove water vapor, carbon dioxide, trace contaminants, and odors, and to control air temperature. It also includes the equipment which processes the CO_2 and the normal oxygen source, water electrolysis. Air ventilation and distribution of reconditioned air is also provided.

Cabin air is continually processed through a condensing heat exchanger which cools the air sufficiently to cause condensation of cabin humidity. The condensate is removed by a static condensate remover and passed to the water management assembly group. A portion of the condenser outlet air is directed to the EDC when carbon dioxide is removed.

The EDC is an electrochemical method for continuously removing CO_2 from a flowing air stream. The removal takes place in an electrochemical module consisting of several cells arranged in parallel but packaged as one unit. The cells consist of a matrix of aqueous carbonate solution with

electrodes located on each side. Passageways are provided adjacent to the electrodes for distribution and collection of gases. The overall chemical reaction is as follows:

$$O_2 + 2CO_2 + 2H_2 \rightarrow 2CO_2 + 2H_2O + \text{Electrical energy} + \text{Heat}$$

Carbon dioxide is passed from the cathode, process air side, to the anode, concentrated CO_2 side, in the form of carbonate ions, $CO_3^{=}$. The reaction also requires the formation of hydroxl ions on the cathode side which migrate to the anode side where they react with hydrogen to form water. These reactions result in the consumption of O_2 and H_2 in a fuel-cell type reaction. Therefore, cabin oxygen is consumed in the reaction, producing water which can be recovered for reuse.

Hydrogen is provided to the EDC unit from an electrolysis cell which also produces makeup oxygen to the cabin. More hydrogen is produced than is required in the EDC unit and this excess mixes with the concentrated CO_2. This mixture, along with a trace of water vapor, passes to the Sabatier reactor, which converts carbon dioxide and hydrogen into water and methane as shown in the following reaction:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

The Sabatier reactor consists of a catalyst bed maintained at a high temperature. There is sufficient H_2 available in the incoming gas stream to react about 60% of the CO_2. The products of reaction leave the reactor as a mixture of gas; the water is in the form of water vapor. The gas mixture is passed through a low-temperature condenser where most of the water is condensed and removed to the water management assembly group. The remaining gas mixture passing through the reactor is vented overboard or used in the reaction control system.

Trace contaminant control is provided by activated charcoal beds for odor control, and a catlytic oxidizer converts low molecular weight contaminants to products which can be removed by other ECLSS components. Continued monitoring of the atmosphere is performed by the trace contaminant

monitoring assembly, which is based on spectrometry and gas chromotography. These instruments monitor key constituents which could inadvertently be generated within the vehicle atmosphere.

Control of air temperature is provided by zone heat exchangers in each module. Cooling water from the thermal control system is circulated on the liquid side of the heat exchangers to cool cabin air passed through the air side by circulation fans. Temperature control is accomplished with a control valve which bypasses coolant water around the heat exchanger as required to maintain cabin air temperature. Sufficient air flow is expected to be required for air cooling to also satisfy ventilation requirements within the habitable volume. This is done by judicious placement of heat exchangers, possible use of ducting for distribution, and incorporation of diffusers to obtain satisfactory air velocity patterns within the volume.

3.2.3 Water Recovery

The water recovery assembly group collects water from the various sources, treats it according to purity needs, sterilizes, stores, and distributes the water as required. Condensate water from the humidity control condenser and the Sabatier reactor condenser is relatively pure and requires only processing by multifiltration and sterilization for potable water. Wash water is less pure and requires more rigorous treatment by hyperfiltration prior to reuse. The wash water is kept separate from the potable water system except for (1) hyperfiltration concentrates, which are processed in the urine water recovery unit, and (2) makeup water from the potable water supply to account for the loss of concentrate and water vapor lost to cabin air. Urine water is the least pure water source, and a concept using a phase change, i.e., vapor compression distillation is required. Water recovered from urine water recovery is relatively pure, and, after treatment by multifiltration and sterilization, is used for potable water.

The multifiltration unit is a static system consisting of colums of ion exchange resin and charcoal and filters. Impurities are removed in the columns; filters remove suspended particles and bacteria.

A key component of the hyperfiltration concept, which is used for recovery of wash water, consists of a module of semipermeable membranes. Wash water from a holding tank is directed to one side of the membrane under high pressure, causing relatively pure water to pass through the membrane. Post treatment is performed on the processed water to remove trace impurities which pass through the membranes. A concentrate solution which does not pass through the membrane is passed to the VCD unit. The purified wash water is stored in a storage tank heated to a sufficient temperature to prevent bacteria growth.

The vapor compression distillation unit for recovering urine water operates on a phase change concept. A rotating distillation still is the key component in the concept. A mixture of pretreated urine and hyperfiltration concentrate enters the center of evaporator portion of the rotating still. The liquid water collects on the outer shell due to the centrifugal force of the rotation. A vapor pump reduces the pressure sufficiently to cause evaporation of the water. The vapor is pumped to the outer annulus of the still where it condenses on the shell of the still. Condensation occurs on one side of the shell; evaporation occurs on the opposite side. The condensate is removed from the surface and pumped through an iodine sterilization unit and then to storage tanks. A high concentration of impurities buildsup on the evaporator section of the still, and this is removed and stored for return to earth.

3.2.4 Thermal Control

Thermal control includes both active and passive means and has the purpose of maintaining Space Station equipment and atmosphere within acceptable limits. Active thermal control consists of circulating fluid loops which collect heat within the vehicle and reject it to space through radiators.

Two separate fluid loops are used in the design because no single fluid is ideally suited for use in and out of the habitable area. A water loop is used internally because of its good heat transport properties and non-toxicity characteristics. The water is circulated through equipment, heat exchangers, and cold plates to pick up waste heat. The condensing heat exchangers

require the coolant temperatures, about 4.44°C (40°F), and these are the first components in the water flow path. Heat exchangers which cool cabin air are located next in the water loop because they also require a cool temperature, ideally about 15.6°C (60°F). Other equipment is located downstream according to temperature needs.

Heat from the water loop is transferred to the freon 21 loop via a high effectiveness liquid-to-liquid heat exchanger (interloop heat exchanger). The freon fluid is then distributed to the radiator tubes located on the surfaces of the modules. As the fluid circulates through the radiator tubes, the heat is conducted to the outer skin on the module and is dissipated by radiation to space. A thermal coating is used on the module surfaces which absorbs little energy of the solar energy wave length, typically 10 to 30%. This surface also has a high emittance in the infrared wavelength, thereby radiating about 80 to 90% of the maximum which can be ideally radiated. This surface characteristic is ideal for use on a space radiator; solar energy is not highly absorbed but a large amount of heat is radiated from the radiator.

Temperature control within the active fluid loops involves maintaining a water outlet temperature from the interloop heat exchanger to about 4.44°C (40°F). Additionally, the freon temperature in the heat exchanger must stay above the water freezing point 0°C (32°F) to prevent the water loop from freezing. This is done through the use of a regenerative heat exchanger in the freon loop which passes sufficient radiator return fluid through the regenerative heat exchanger to maintain a 1.67°C (35°F) inlet freon temperature to the interloop heat exchanger. All of the radiator outlet freon flow passes through the second side of the heat exchanger. This control method has the advantage of precise control over a wide disparity between radiator capability and cooling requirements.

Many Space Station elements, especially structure, cannot be efficiently controlled thermally by the active systems. Passive thermal control is a more appropriate method in these cases. Passive thermal control of the structure involves use of superinsulation to maintain the pressure shell

within tolerable limits, normally above 15.6°C (60°F) to prevent water vapor condensation on internal walls. The upper limit to pressure shell wall temperature can be set by local crew touch temperature, 40.6°C (105°F), or by the allowable heat loss or leak through the structure. In addition to the use of superinsulation, use of nonconductive materials, localized electric heaters, and special thermal coatings are used in the passive thermal control of the structure. These same basic methods are also used to control other equipment located external to the pressure shell. Passive thermal control is particularly applicable to equipment of low power density and large allowable temperature ranges.

3.2.5 Emergency ECLSS

A 180-hr emergency ECLSS provides all essential ECLSS functions for the time period required for emergency rescue in LEO by the Shuttle. This self-contained unit is packaged on a pallet which can easily be installed or removed from the Space Station with a minimum amount of interface connections. The unit will be designed to accommodate expected increments in crew buildup, for example 7 men. Sufficient total capacity is required for the largest on-board crew, such as double crew when crew rotation occurs.

The emergency ECLSS provides the following functions:

- Oxygen for crew breathing and module leakage.
- Water for crew intake and cooling.
- LIOH for CO_2 control.
- Water boiler for cooling.
- Miscellaneous crew systems provisions.

Design of the unit is to provide the "bare essentials" to the crew in an emergency situation.

Part 3

HIGH-VOLTAGE ARRAY PLASMA EFFECTS

HIGH-VOLTAGE ARRAY PLASMA EFFECTS

INTRODUCTION

Satellite power system (SPS) design is based on a high-voltage solar array output to keep system weights and sizes within practical bounds. However, the low-energy charged-particle densities in low earth orbit (LEO) constitute a plasma interface that is expected to cause a current drain which may reduce the arrays' power output to zero. These losses are functions of solar array voltage, array size, and orbit altitude. The latter dictates plasma density, which is at a maximum in the LEO ionosphere, where the low-energy electron and proton quantities are several orders of magnitude greater than at GEO. Plasma power losses as functions of orbital altitude and array voltage are shown in Figure 1.

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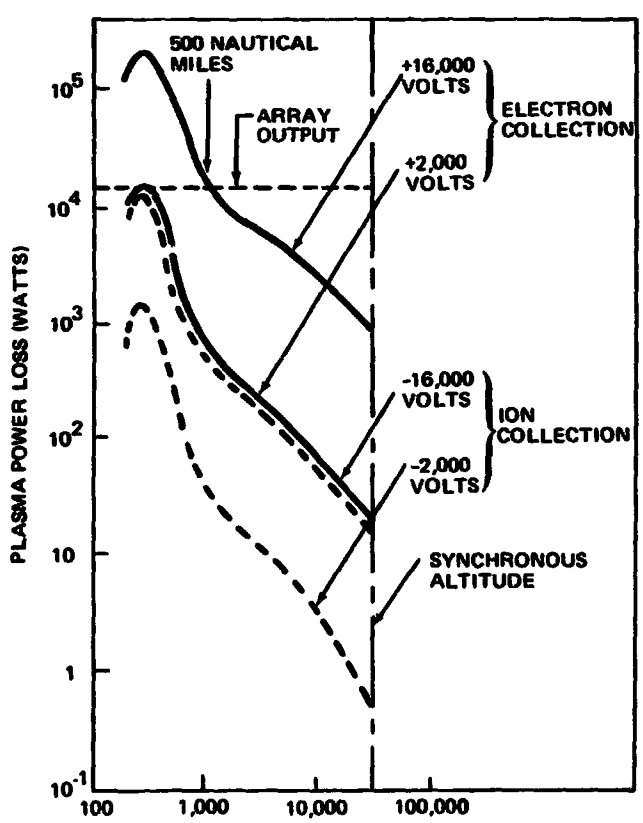

Figure 1.

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The predicted loss rates for high-voltage solar arrays could make the proposed SPS testing of array and power antenna at LEO impractical without significant SPS changes.

SUMMARY

A detailed experimental investigation of the interaction between a high-voltage solar array and a simulated space plasma has been conducted in a vacuum chamber (Reference 1). The investigation considered pinhole failures common to the normal insulating and encapsulating covers, plus the plasma current power leakage and physical damage that can result from space plasma particles collected by exposed high-voltage conductors, such as the bare interconnections between solar cells. Exposed conductors of a solar array may be at large voltages of either polarity relative to the space plasma. Calculations for the lower regions of the ionosphere indicate that the plasma currents collected by the bare high-voltage interconnectors would result in power losses comparable to the total array output.

The referenced study recognized the need for additional testing and for space test data to confirm the experimental calculations. Space test data was to be obtained from the SPHINX (Space Plasma High Voltage Interaction Experiments) satellite in 1974; however, the launch failed and the next satellite launch is now scheduled for 1980. Current plans (Reference 2) call for space test data to verify the plasma interactions and to provide bench marks for ground testing in vacuum chambers.

SPHINX satellite test data should be obtained to determine the magnitude of the problem and to permit final determination of changes necessary for the SPS to conduct the desired test program in LEO. Possible options include array operation at low voltage, extensive solar array insulation, and unmanned test at altitudes above 500 nmi.

Review of the space plasma leakage effects in LEO has led to speculation about potential problems in other areas, as follows:

- o Plasma-induced power leakage within the phase-control electronic equipment, which may lead to malfunction of the beam steering equipment.

- Plasma-induced leakage in the amplitrons and waveguides, which could cause loss of power transfer capability.

- Plasma leakage inducing RF interferences, which could make it extremely difficult to instrument and control the SPS operation.

Any of the above potential problems could cast doubt on the feasibility of LEO test of either TA-1 or TA-2.

DETAILS

The current SCB approach proposes LEO testing of the SPS TA-1 and TA-2 for the purpose of assessing the technical and economic feasibility of large satellite power generation stations. Proposed testing will include evaluation of microwave power transmission and end-to-end space construction/system performance verification.

Concern over the interaction of LEO space plasma with the high-voltage arrays has arisen as a consequence of the experimental investigations (Reference 1) which tested solar array samples with a plasma source in a space vacuum chamber. The investigation indicates that the plasma interaction extent is of concern primarily in the ionosphere region from 100 to 500 nmi because of low-energy high-density charged particles. Reference 1 has projected significant potential power loss consequences, as shown in Figure 2, for a LEO solar array size of 1,500 ft^2 (15,000W output). The projections are based on experimental data with solar array segments of 1 ft^2 area and solar plasma interaction equations from original work done by Langmuir in 1924. Figure 2's specific plasma density at 300 km is assumed to be 4×10^6 electrons/cm^3. (The predicted loss rates reflect maximum particle densities and will be less severe during minimum solar activity.) As indicated, the plasma current leakage rates at 16,000v are more than enough to dissipate all the array output. Figure 3 is taken from Reference 1 also, and indicates the significant dropoff in leakage rates at geosynchronous altitudes where the electron density is lower by four orders of magnitude and the electron energy is significantly higher.

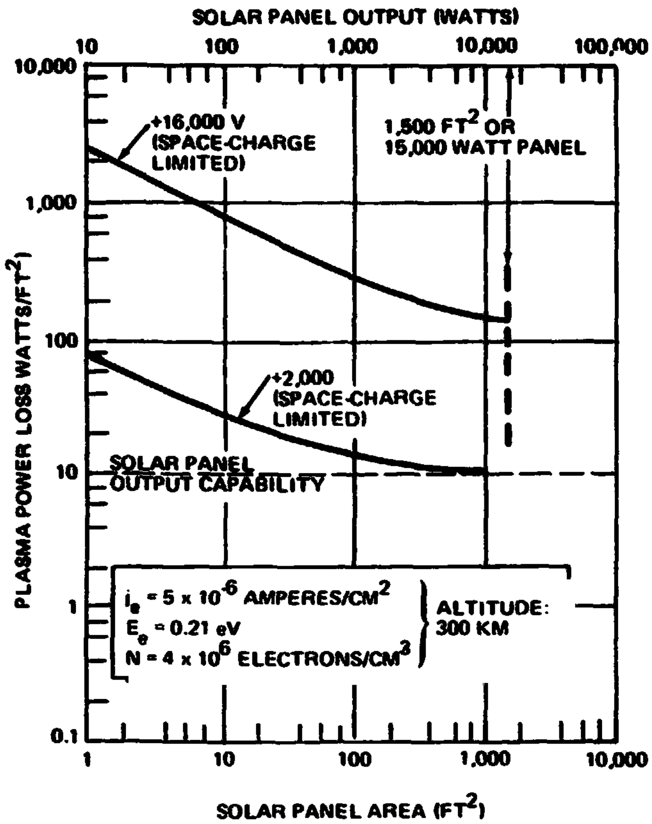

Figure 2

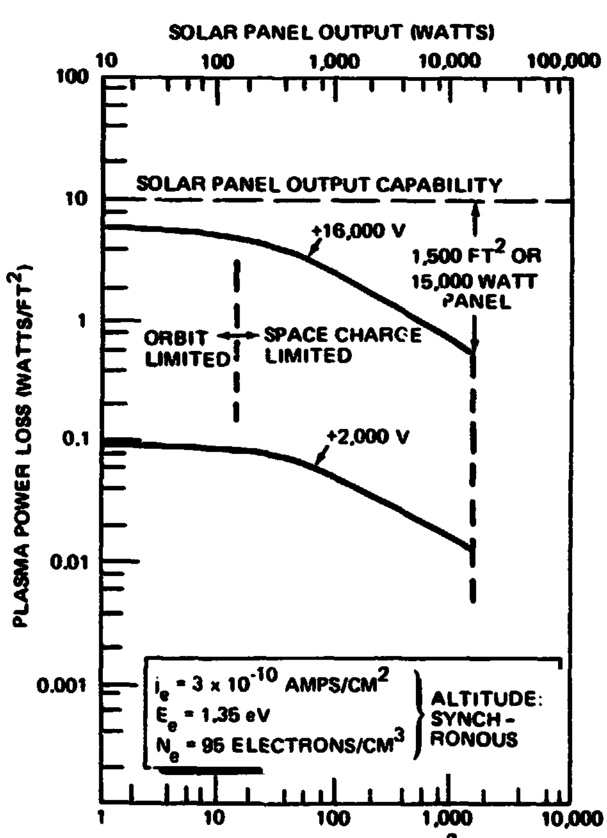

Figure 3

The uninsulated interconnections between solar cells will be at increasing voltages depending on the cells' position within an individual string, and the connections will act as biased plasma probes attracting or repelling charged particles. At some location on the array the generated voltage will be equal to the space plasma potential. Electrons are attracted to the connections which are at voltages above the plasma potential. At voltages less than the plasma potential, the connections will attract protons. The consequent particle flow is a plasma current loop in parallel with the SPS load and will reduce the power available from the array. This phenomenon is illustrated in Figure 4.

Experimental work at NASA/Lewis Research Center (Reference 2) verified the earlier work done at the Boeing Aerospace space chamber. This LeRC work also verified the Reference 1 observations on pinpoint failures in the solar array insulation, with attendant large plasma electron currents. The considerable difficulty encountered by Boeing in obtaining insulation that was free of pinholes or thin spots shows that it can be extremely difficult to provide leak-free insulation on the TA-2 assembly. (Reference 1 reported complete destruction of solar cell interconnections that had been covered by adhesive material.)

CR5

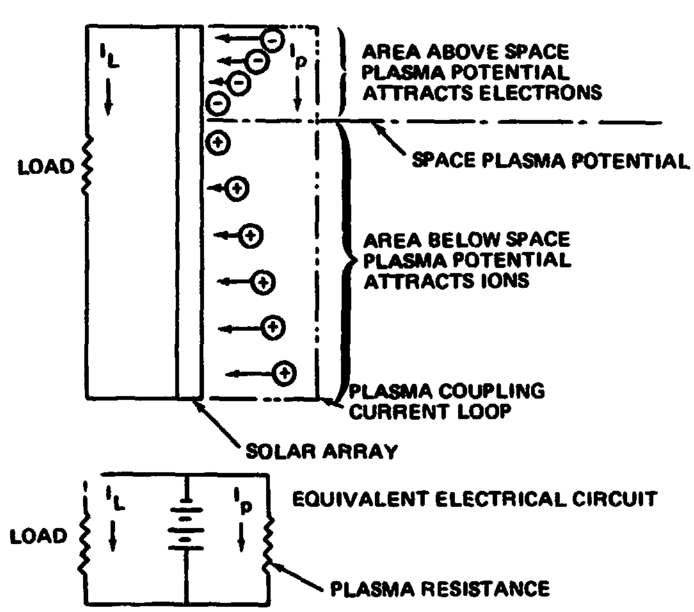

Figure 4.

Since the plasma pinhole current potential increases with array size, the weight penalty for "adequate" insulation will be high, and the space environment of micrometeoroids, thermal cycling, ultraviolet radiation, etc., offers risk of pinholes despite significant insulation care. Vacuum chamber tests were made on Kaptron, FEP Teflon, fused silica, and glass, as well as silicon insulating materials. Evidently, all have pinhole defects or thin spots which can fail within a short time at high-voltage space plasma conditions.

Lacking firm space plasma measurements, it appears that significant SPS system design changes would be necessary to permit TA-2 testing in LEO. Change options include array operation at lower voltages (weight and size penalties), extensive and heavy insulation application (with TBD risk), or testing at a higher orbit altitude where space radiation will exclude man and will cause rapid solar cell degradation.

It is important to obtain SPHINX satellite test data since it is possible that the results may show less severe plasma interaction than has been calculated. The 1980 flight schedule coincides with the next solar maximum and if the plasma leakage rates are lower than predicted levels, design modifications needed for the TA-2 power test could be less extensive.

REFERENCES

1. CR-12180, Final Report High Voltage Solar Array Experiments, Contract NAS3-14364, by K. L. Kennerud, Boeing Aerospace Company, March 1974.

2. Engineering Paper, Solar Array Experiment on the SPHINX Satellite, by N. John Stevens, NASA LeRC, IEEE Photovoltaic Specialists Conference, November 1973.

Part 4

CRANE OPTIONS

CRANE OPTIONS

The crane represents a major subsystem of the space construction base fabrication and assembly facility. The SCB operational buildup and construction characteristics defined in Section 10 of Volume 2 require assembly of the SCB, the large space structures, and support of the local logistics. Each can be satisfied by two basic system options: a crane or a local Tug. Consideration of these options led to the selection of the mobile crane because of flexibility in construction, positive berthing, and safety. Several crane options were investigated. These options included a rail-mounted crane, a swing-boom configuration, a stationary version and a mobile crane. Figure 1 is a summary of the direct comparison between candidate configurations.

RAIL-MOUNTED CRANE

The rail-mounted crane, shown in Figure 2, incorporates two manipulator arms mounted to a revolving body. The crane body includes the appropriate docking/berthing mechanism to enable it to interface with various SCB modules and/or the Orbiter. The crane body is mounted on a rail system which provides axial mobility and controlled motion. Teleoperation control is effected from within the SC operations module.

Although the rail-mounted crane provides good axial mobility, it results in reduced berthing port availability and only two-dimensional mobility. As illustrated, the crane rail blocks all berthing ports in the Z axis of the SCB to provide a clear corridor down the X axis. In addition, a method to transverse the solar array turret would be required. After evaluating the pros and cons, this concept was rejected.

SWING-BOOM CRANE

The swing boom crane shown in Figure 3, incorporates two manipulators mounted on the crane body which traverses the swing boom. The swing

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RAIL TRANSFER	SWING BOOM	MOBILE – WALKING	STATIONARY MOUNT
PROS			
• GOOD AXIAL MOBILITY • CONTROLLED MOTION • RAIL POWER/ COMMANDS LINK	• ALL BERTHING PORTS AVAILABLE • CONTROLLED MOTION • RAIL POWER/ COMMANDS LINK	• 3-D MOBILITY • SCB GROWTH FLEXIBILITY • SPACE CONSTRUCTION VERSATILITY	• LEAST COMPLEX • POWER AND COMMAND LINK HARDWIRED
CONS			
• CLEAR CORRIDOR • 2-D MOBILITY • RAIL BLOCKS BERTHING PORTS • BRIDGE AT SOLAR ARRAY TURRET	• COMPLEXITY • CANTILEVIER BEAM LENGTH • SPACE CONSTRUCTION INTERFERENCE • CLEAR CORRIDOR	• REQUIRES BERTHING PORT • POWER PICKUP PADS	• TWO CRANES REQUIRED • CLEAR CORRIDOR • HANDOFF ITEM TRANSFER • SCB GROWTH CONSTRAINTS

Figure 1. Subsystem Option SCB Crane Trades

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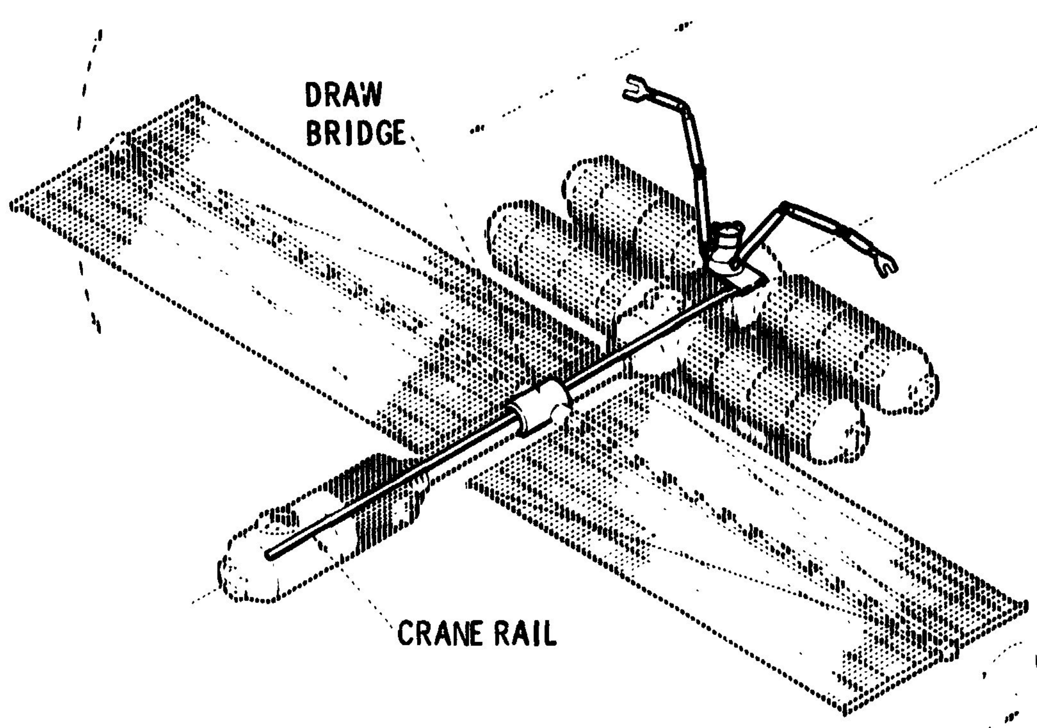

Figure 2. Rail-Mounted Crane

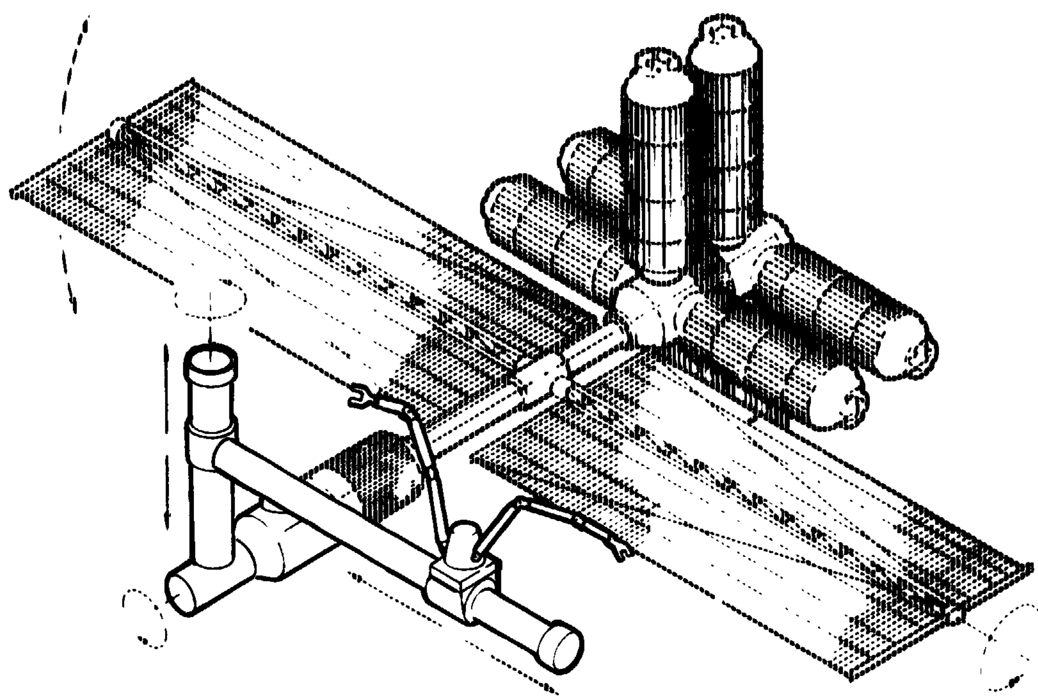

Figure 3. Swing-Boom Crane

boom mounts to the SCB as part of the space construction operations module on a vertical pivot post. The vertical post allows access to any point in the X-Y plane of the -Z axis of the base and most points on the +Z axis. Access to any of these points is limited by interference from construction or operational modules. The swing-boom concept eliminates the clear corridor restrictions imposed by the rail-mounted version, but requires a long, movable cantilever beam. The complexity of such a concept, plus the possibility of objective element interference resulted in rejection of the swing-boom concept.

STATIONARY-MOUNT CRANE

The stationary crane, shown in Figure 4 is the least complex of all the concepts. Because of its stationary feature, two cranes would be necessary to assure access to all parts of the SCB. The concept incorporates two remotely controlled manipulator arms attached to a revolving body section. The body section is configured to interface with any discrete SCB berthing port. The body section is designed to permit shirtsleeve maintenance of the

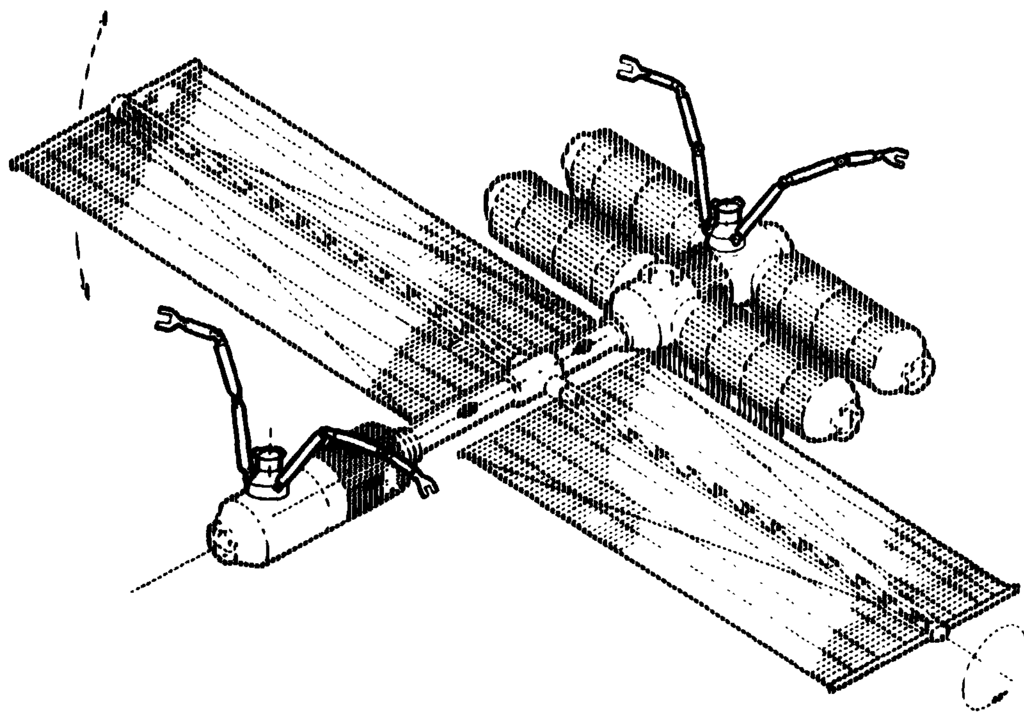

Figure 4. Stationary-Mount Crane

mechanical devices. In addition, the body section provides emergency EVA and/or rescue capabilities through the crane interface. Location of the crane on the SCB will depend on the mission objective element being constructed.

The crane command system, power, and video display consoles are located in the SC operations module and hardwired to each crane.

Although it is the least complex, the stationary-mount concept requires two cranes, and the transfer of items or modules axially would necessitate a hand-off mode of operation. As the result of the above, the stationary mode was rejected in favor of the mobile crane concept.

MOBILE CRANE

The mobile crane concept, shown in Figure 5, is extremely versatile. Although it requires a berthing port, and must either contain its own power supply or have power pickup points at numerous locations, it possesses the capability for full three-dimensional mobility. In addition, it can be moved to any large structure to aid in assembly operations.

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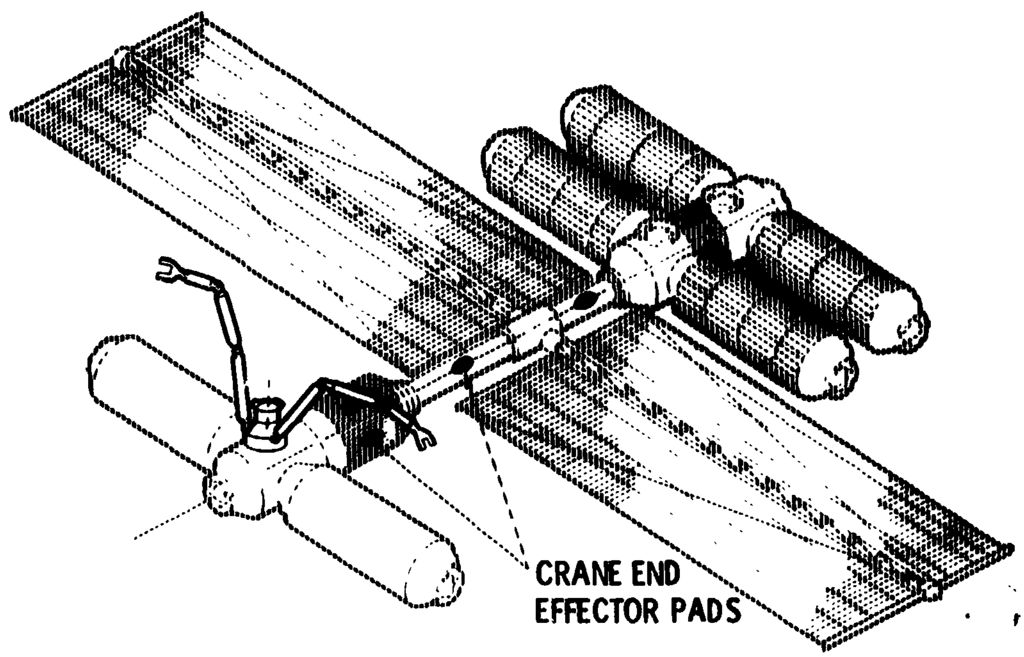

Figure 5. Mobile Crane

The SCB baseline crane system consists of two manipulator arms mounted on a 2.23m (88-in.) dia. body section and a control station located in the SC control and support module. The manipulator arms can be operated sequentially and simultaneously.

Basic Functions

The mobile crane system is capable of performing the following space operations:

- Large space structure assembly
- Removal of payloads from the Orbiter P. I. D. A. system and deploy to a stabilized berthed position.
- Configuration and reconfiguration of the SCB assembly.
- Stabilization of payload logistic elements and transportation to assembly position.
- Transportation of EVA crewman.

Operation

The mobile crane system is configured for a two-man console operation located in the SC support and control module as shown in Figure 6. Four manipulator operational modes are required:

A. Remote control (manual or aided manual)
B. Robot (automated)
C. Combined modules
D. Cherry picker (direct visual and manual access at point of work)

The remote control mode will permit operation from any one of the three systems: central control station, crane base using direct vision, or the cherry picker end effector. The automated mode would allow the crane to be programmed to perform repetitive tasks automatically. Incorporated in the program would be a clearance envelope and a position-hold autopilot system.

The combined mode would enable the operator to control one arm manually from the various control positions, while allowing the second arm to perform its programmed tasks. In addition to the above, it will be necessary for the EVA crewman to have direct manual control of both crane arms at the point of work. Therefore, control capability will be required from the cherry picker platform. It will also be necessary to provide manual controls at a position where the operator has direct vision of the work area and the location of each EVA crewman to enable the operator to assist the crewman at the direct point of work.

System Description

The selected system configuration is shown in Figure 5 and consists of two manipulator arms, a crane body section, and a command control system.

Manipulator Arm

The manipulator arm is a 35m (114 ft) long, 0.6m (24-in.) diameter tabular structure consisting of upper and lower arms, wrist assembly, and end effector. Both upper and lower arms are 15m (50.5 ft) long between pitch joints. The wrist assembly is 4m (13 ft) from the pitch joint to the tip of the end effector. Six joints provide six degrees-of-freedom for handling payloads in the zero-gravity environment. The geometry is shown in Figure 7.

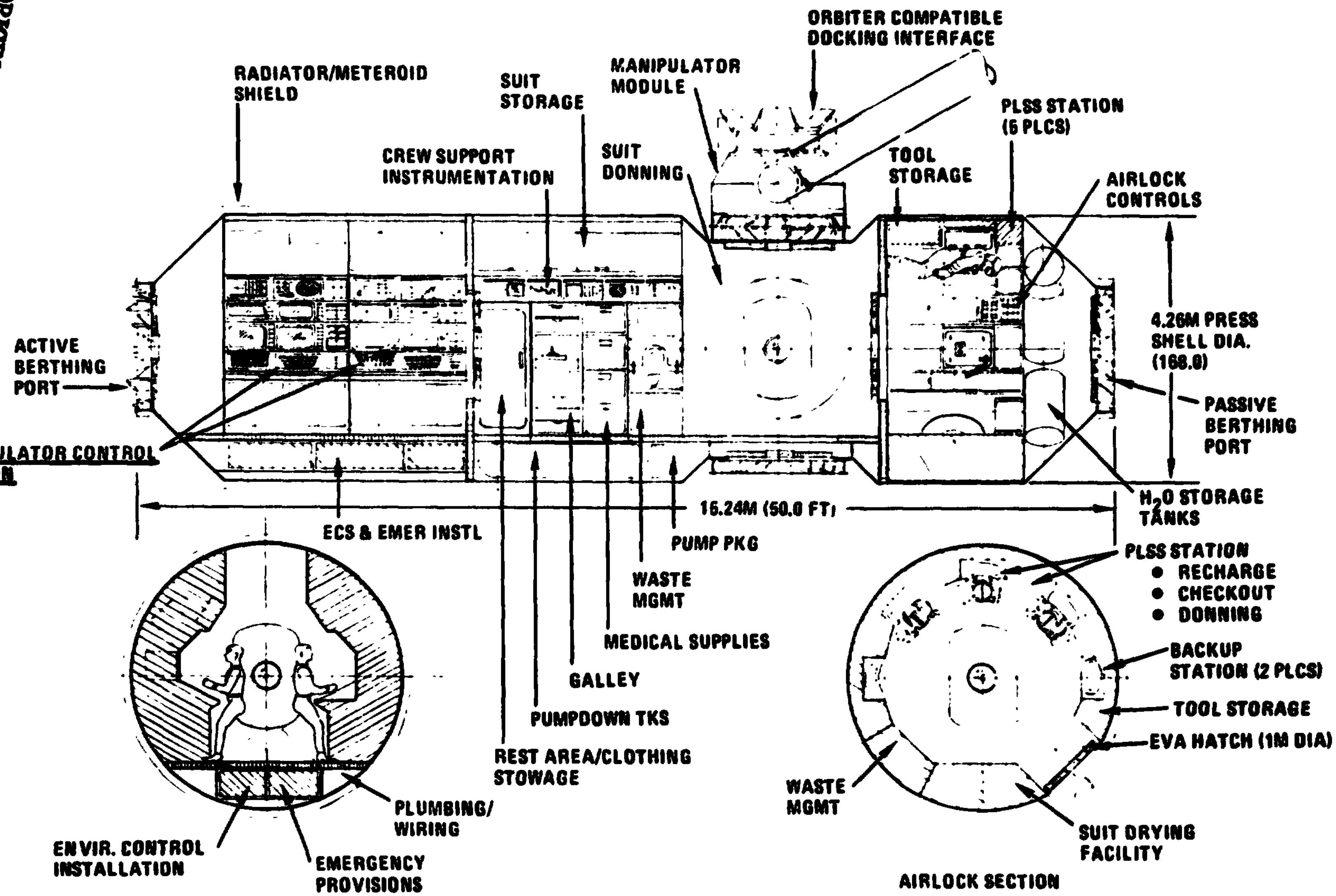

Figure 6. Space Construction Support Module

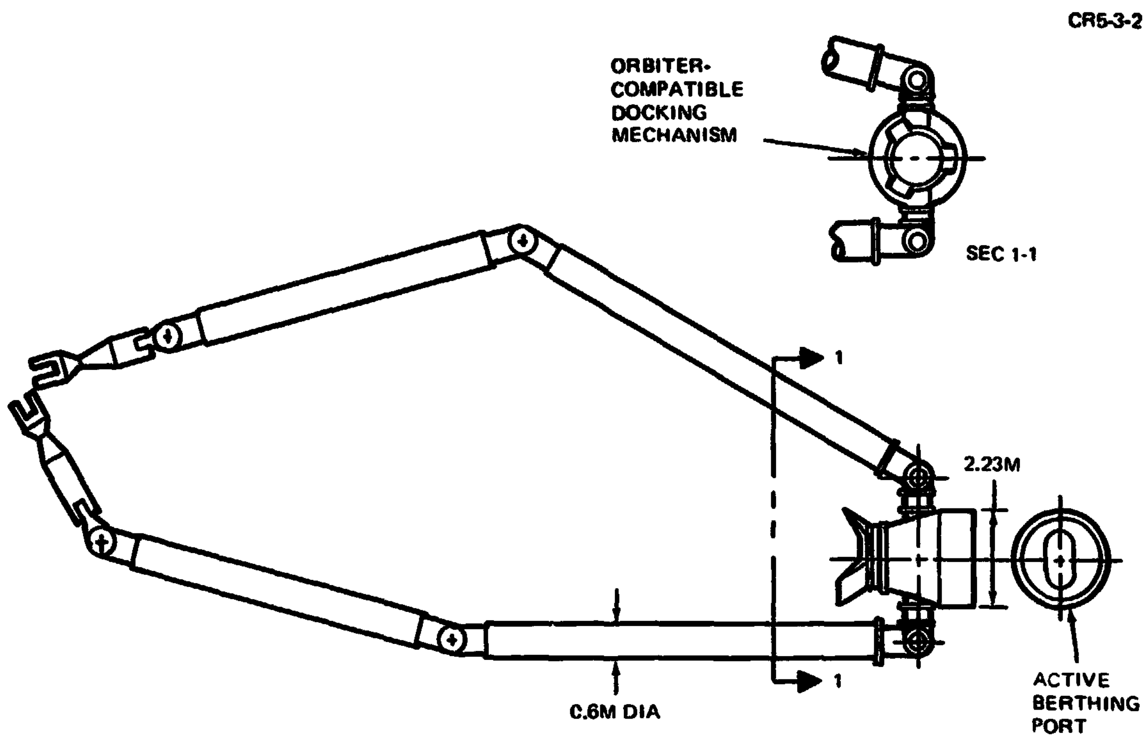

Figure 7. Mobile Crane Geometry

Body Section

The body section, shown in Figure 8 is 2.23m (88 in.) in diameter X TBDm (TBD in.) long and incorporates an active berthing port assembly plus an international docking mechanism. The active berthing port assembly contains rings, seals, latches, wedge, and guides to mate with the passive berthing assemblies and effect a sealed interface. The incorporation of an active port assembly permits the crane to interface with any berthing port on the SCB.

Dynamic Characteristics

The preliminary dynamic analysis assumed a very simplified arm motion. It is assumed that a 32,000 lbm mass is swung through 180 degrees with a fully extended 35m crane arm. It is highly unlikely that a transfer would be made in exactly this manner. However, it provided a conservative estimate of torque, power, and energy requirements as well as a basis for parameterization of transfer time and stopping distance. Figures 9, 10, and 11 present torque, power, and energy requirements in that oraer. These figures do not, however, include orbital effects. Time required for the hypothetical transfer is parameterized from 5 to 90 minutes. Continuous torque as well as torque

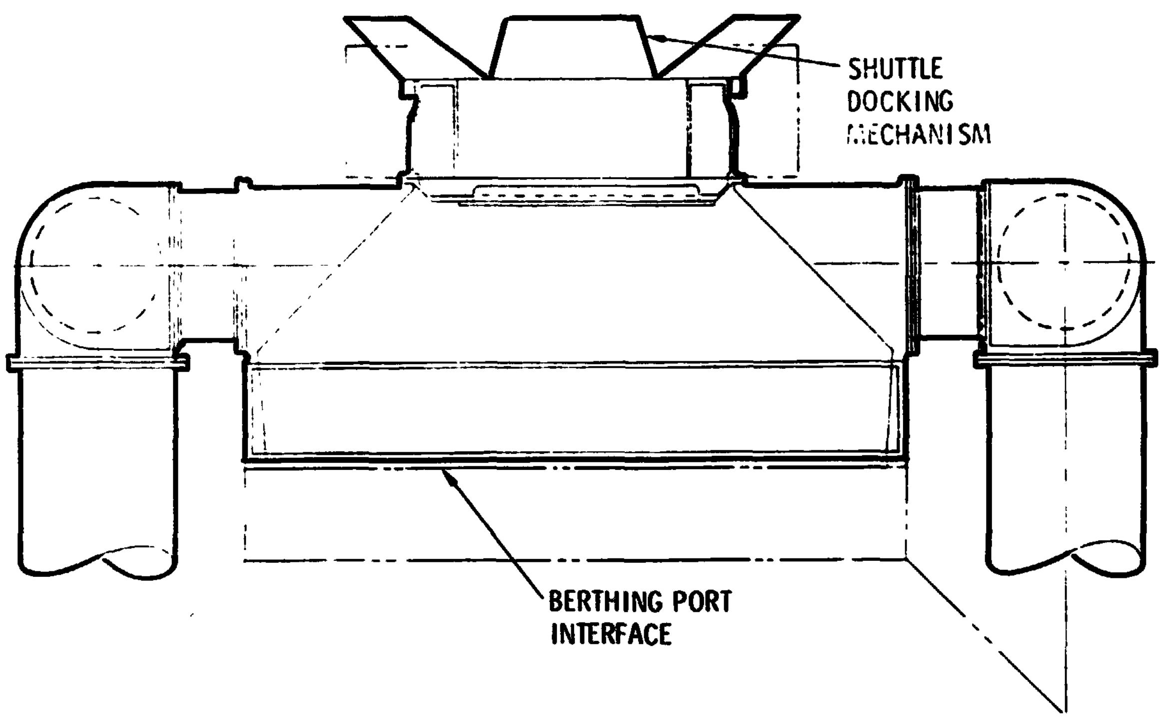

Figure 8. On-Board Two-Arm Crane Module

applied only at the beginning of the transfer are considered. In the latter case, the distance through which the mass travels while the arm is under torque is also the distance which would be required to stop the motion. Safety considerations would favor a relatively short stopping distance. Distances of 0.6, 1.5, and 3.0m (2, 5, and 10 ft) were considered. The continuous torque case corresponds to roughly a 54m (180-ft) stopping distance. An examination of Figure 10 shows that shoulder torque, and its associated normal tip force vary over three orders of magnitude for the range of transfer times considered. For a given transfer time the effect of stopping distance on torque requirement is highly nonlinear. Torque and tip force for a constant stopping distance vary in a manner inversely proportional to transfer time squared.

The shorter the stopping distance, the higher the torque requirement. The power requirements in Figure 10 are more drastically affected by transfer time. They are inversely proportional to the transfer time cubed. As a

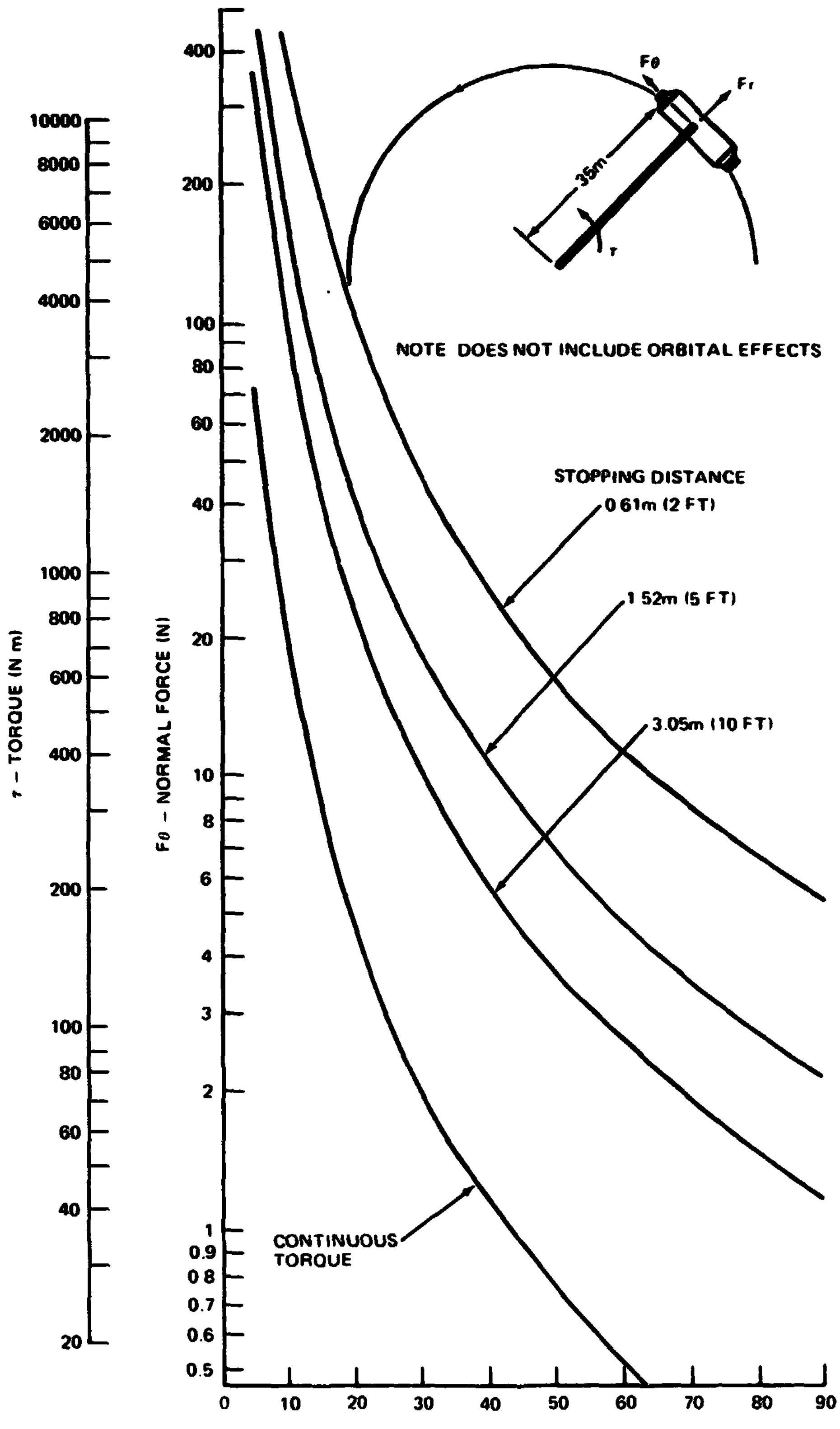

Figure 9. Zero-G Crane Order-of-Magnitude Torque and Tip Force Requirements

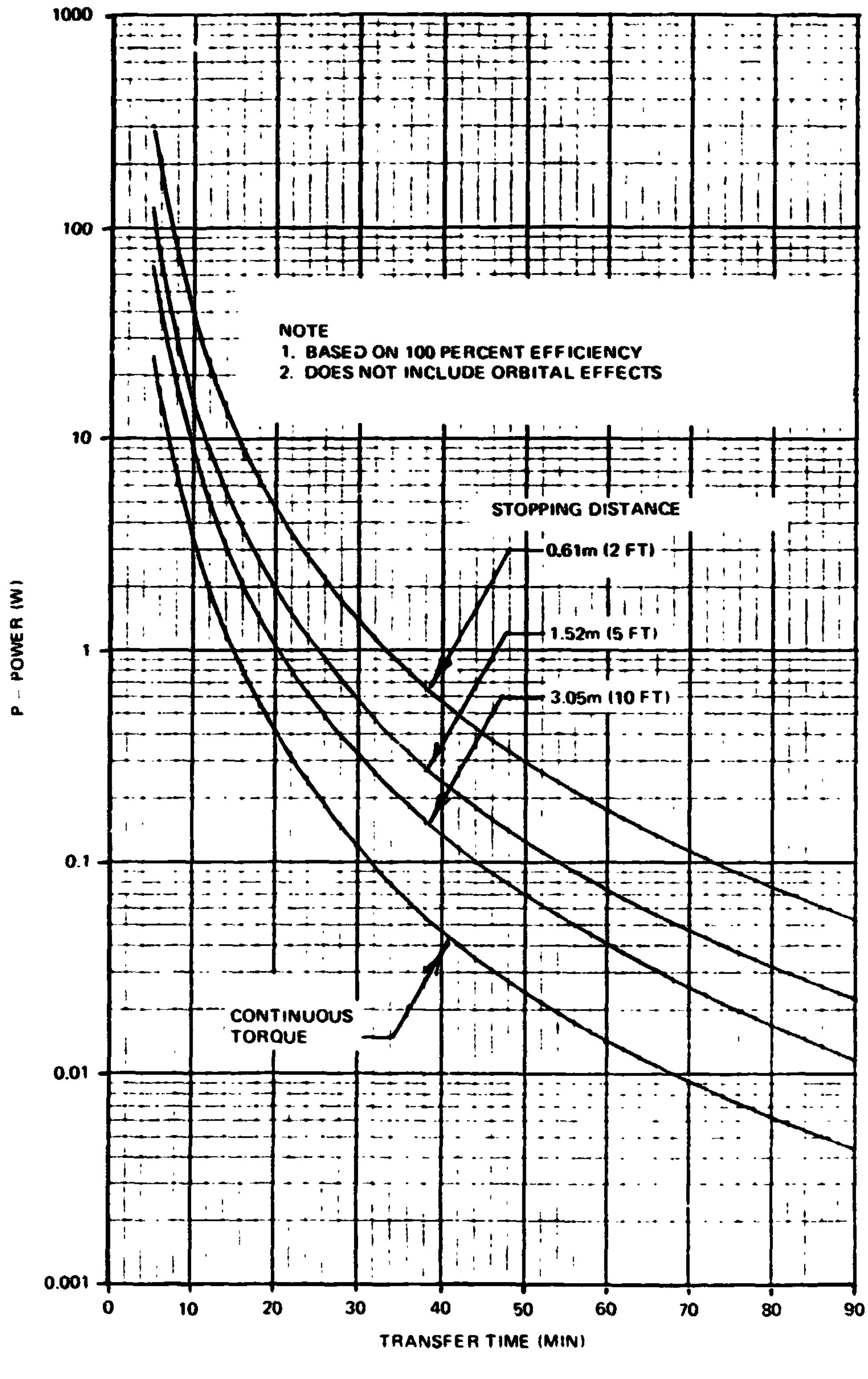

Figure 10. Zero-G Crane Order-of-Magnitude Power Requirement

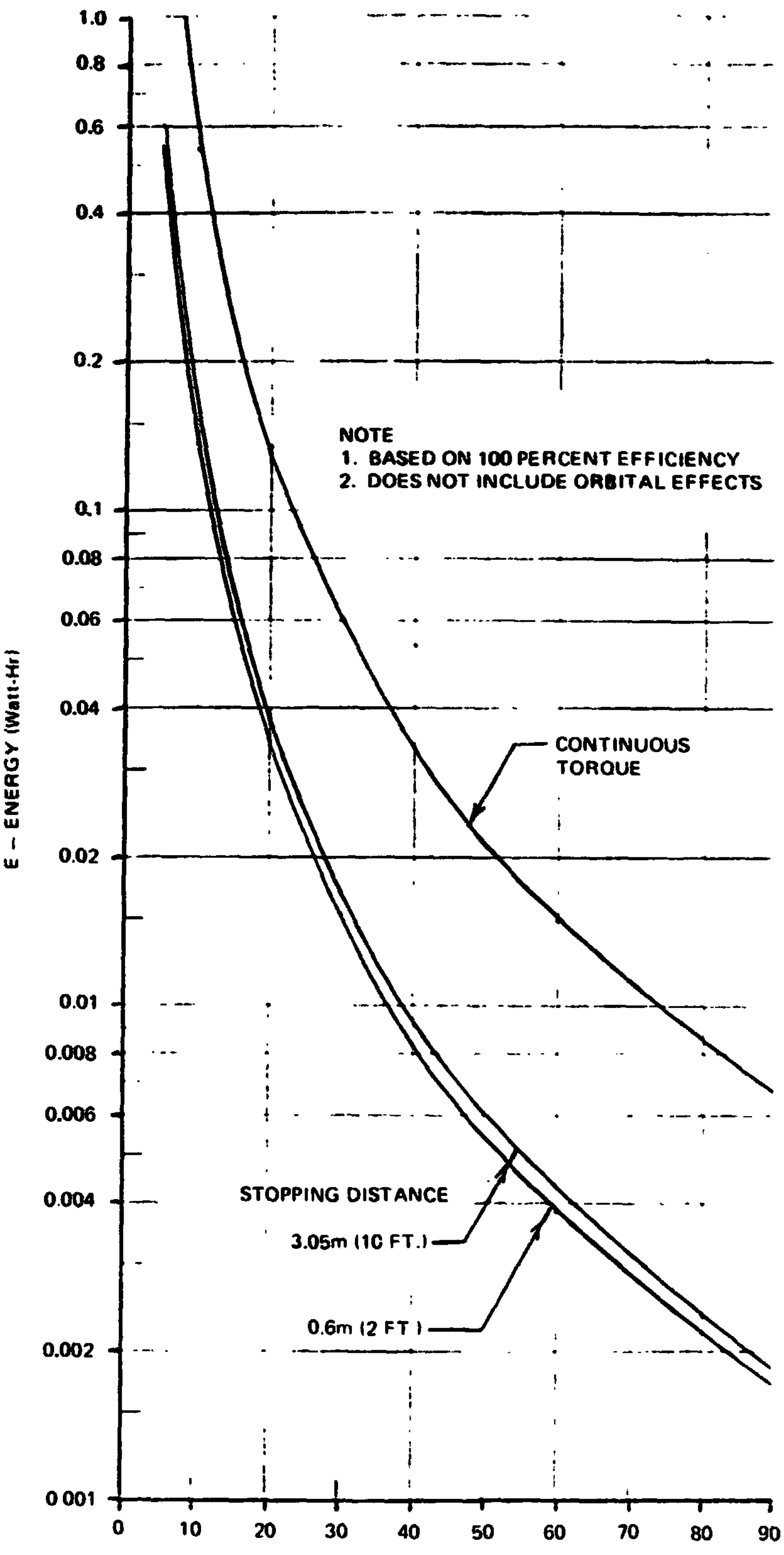

Figure 11. Zero-G Crane Order-of-Magnitude Transfer Energy Requirements

result, the variations in Figure 10 cover almost 6 orders of magnitude. The relative effect of stopping distance is approximately the same. When energy requirements are considered in Figure 11 everything is reversed. The shorter the stopping distance, the less the total energy required for the transfer. For a given transfer time the effect of stopping distance is not as nonlinear as it is with torque and power requirements. For a constant stopping distance, energy requirement varies in a manner inversely proportional to transfer time squared.

Up to this point, no orbital effects have been considered in our hypothetical crane transfer. Figure 12 represents an effort to evaluate how significant these effects might be. The figure presents tip force perpendicular to the crane arm (F_θ) as a function of time for a 30-minute transfer with a 0.6m (2-ft) stopping distance. Due to symmetry, only the first half of the transfer is considered. Segment A is under a constant angular acceleration and segment B is at a constant angular rate. If the SCB were in a void, F_θ would be a constant during segment A, and zero during segment B as is shown by the solid line in the figure. In order to evaluate orbital effects, use was made of the same orbit coordinate system and linearized equations discussed in Section 2.1. The dashed line corresponds to F_θ for a translation along the Y axis of the orbit system with a displacement in the X direction. During segment A, the force required is almost identical to the force required in a void. During segment B, the force required due to orbital effects rises to about 0.09 kgf (0.2 lbf) and then goes back down. Although this is very small compared to the segment A torque, it is continued for a much longer time. The total area under the force/time curve is increased by almost 50% For a Y translation with Z displacement (long and short dashes) the effect is more pronounced with 15% increase in area. In conclusion, the orbital effects appear insignificant in terms of maximum torque and power requirements but quite significant in terms of energy requirements.

The international docking system is an androgynous unit designed to function on either an active or passive mechanism for docking and undocking with an identical system. The system has three guides, 120 degrees apart around an

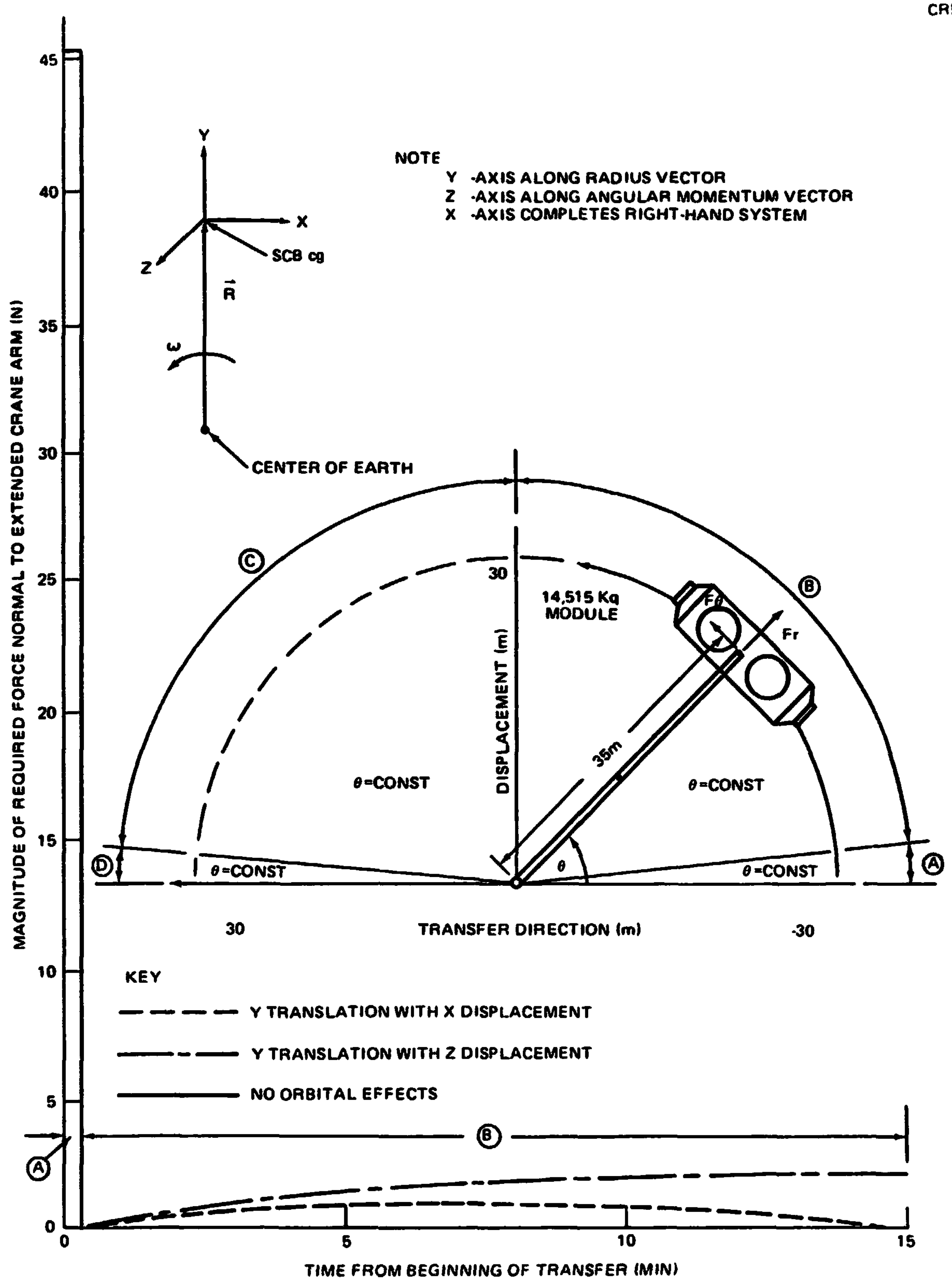

Figure 12. Module Transfer With Crane Orbital Effects Perpendicular to Crane Arm

extendible guide ring. Impact energy is dissipated on the active system by six hydraulic attenuators. The incorporation of the international docking mechanism adds the advantage of providing a direct interface with the Orbiter docking module. This has the advantage of supporting crew rescue from an isolated module by docking the Orbiter to the crane. The crane thereby becomes an airlock to effect crew rescue. Also, it provides an interface with the Orbiter at any of the SCB berthing ports by locating the crane to the selected docking position. A 1.0m (40 in.) dia. hatch is incorporated at each docking/berthing interface with appropriate viewports.

End Effector

An end effector will be provided for all payload handling operations with the capability to exchange end effectors at the work position. End effector concepts for payload handling are shown in Figure 13. In the EVA crewman restraint capacity, the crane manipulator arm would utilize a portable cherry-picker work station as the end effector thus enabling the crewman to be exactly positioned at the work site. Various work station concepts are shown in Figure 14.

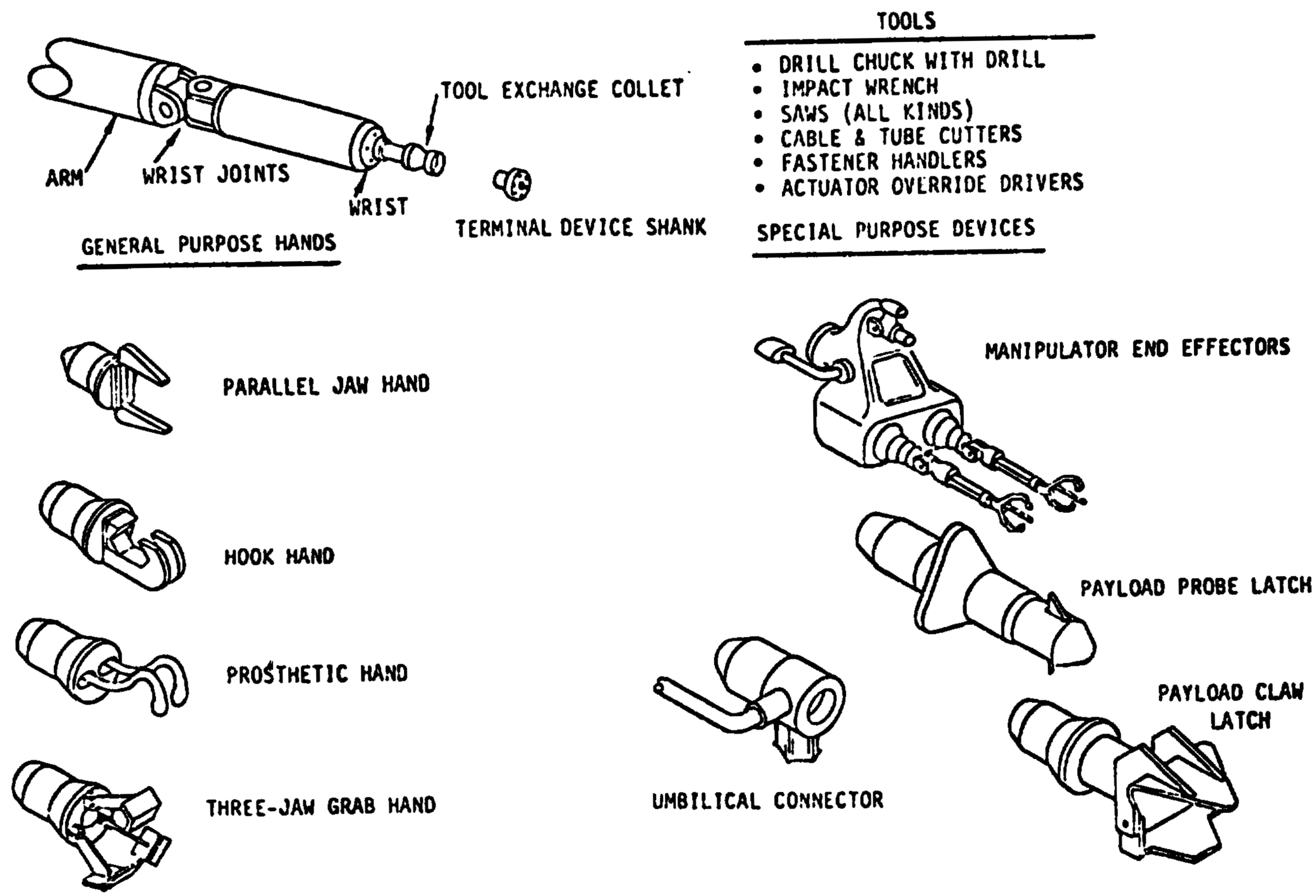

Figure 13. End-Effector Concepts

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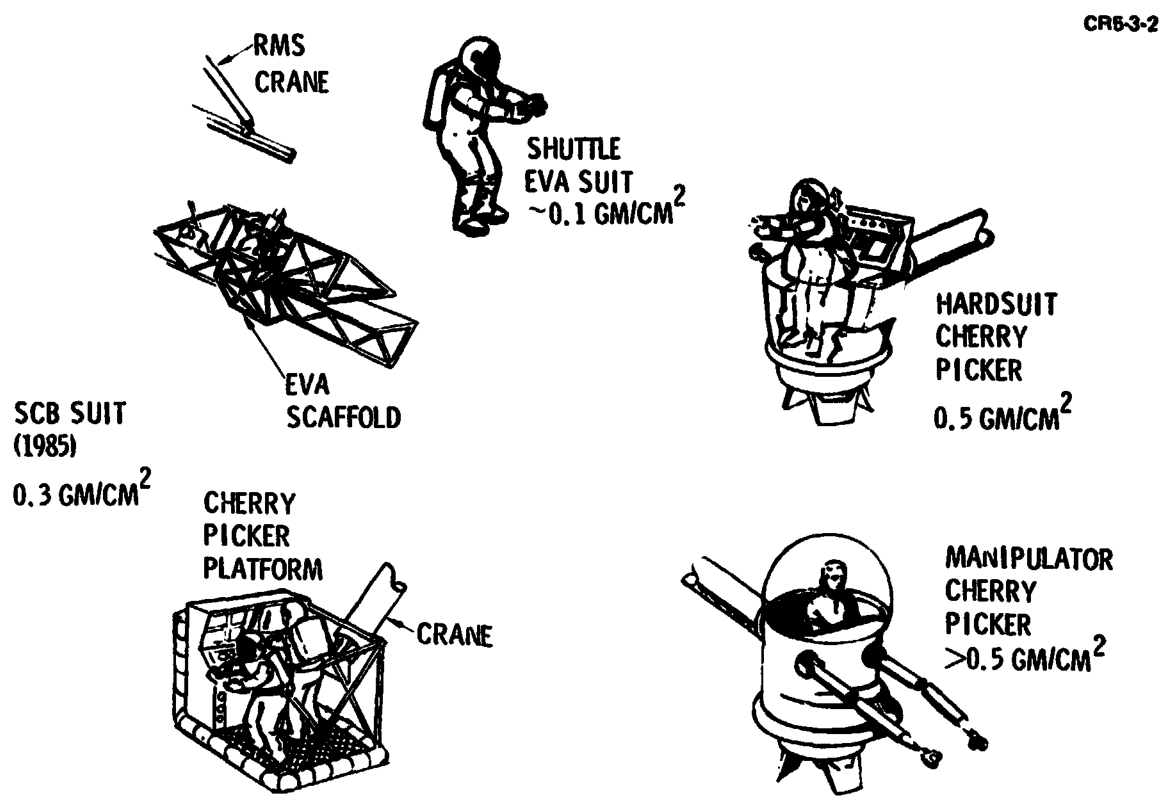

Figure 14. EVA Work Station Concepts

Part 5

LOW-COST MODULE STUDY

LOW COST MODULE STUDY

The purpose of this portion of the study was to determine how much influence the selected design had on the Space Station module cost. By developing cost data for several candidate design options, the study aids in the selection of the least expensive option consistent with uncompromised manned safety.

The module configuration with Orbiter mounting points shown in Figure 1 was selected for the study. The 17.68m (58-ft) length was arbitrarily selected to match some construction base configurations developed earlier in the Space Station study and currently obsolete, but should serve to magnify the delta cost for integral machining the pressure shell cylinder.

The 27,216 kg (60,000 lb) module gross weight equals the Orbiter payload capability to a 220-nm 28.5° orbit with integral Orbiter maneuvering system tankage. It was arbitrarily selected to make maximum use of the available payload capability but serves also to emphasize cost rather than weight savings in development of candidate structural design options.

The launch reactions derived from the 27,216 kg (60,000 lb) module weight and selected attachment locations are shown in Table 1. The module cg at Station 1015 is located as far forward as permissible with a 27,216 kg (60,000 lb) payload. The Orbiter angular rates and the dynamic response of the module to the launch environment are neglected in this simplified loads analysis which illustrates the approximate magnitude of the concentrated reactions that must be distributed to the pressure shell during each mission phase. The loads at entry and landing are included to cover an abort and are not planned.

The damage resistance of the pressure shell must be sufficient to preclude explosive decompression from any reasonably conceivable accident. The

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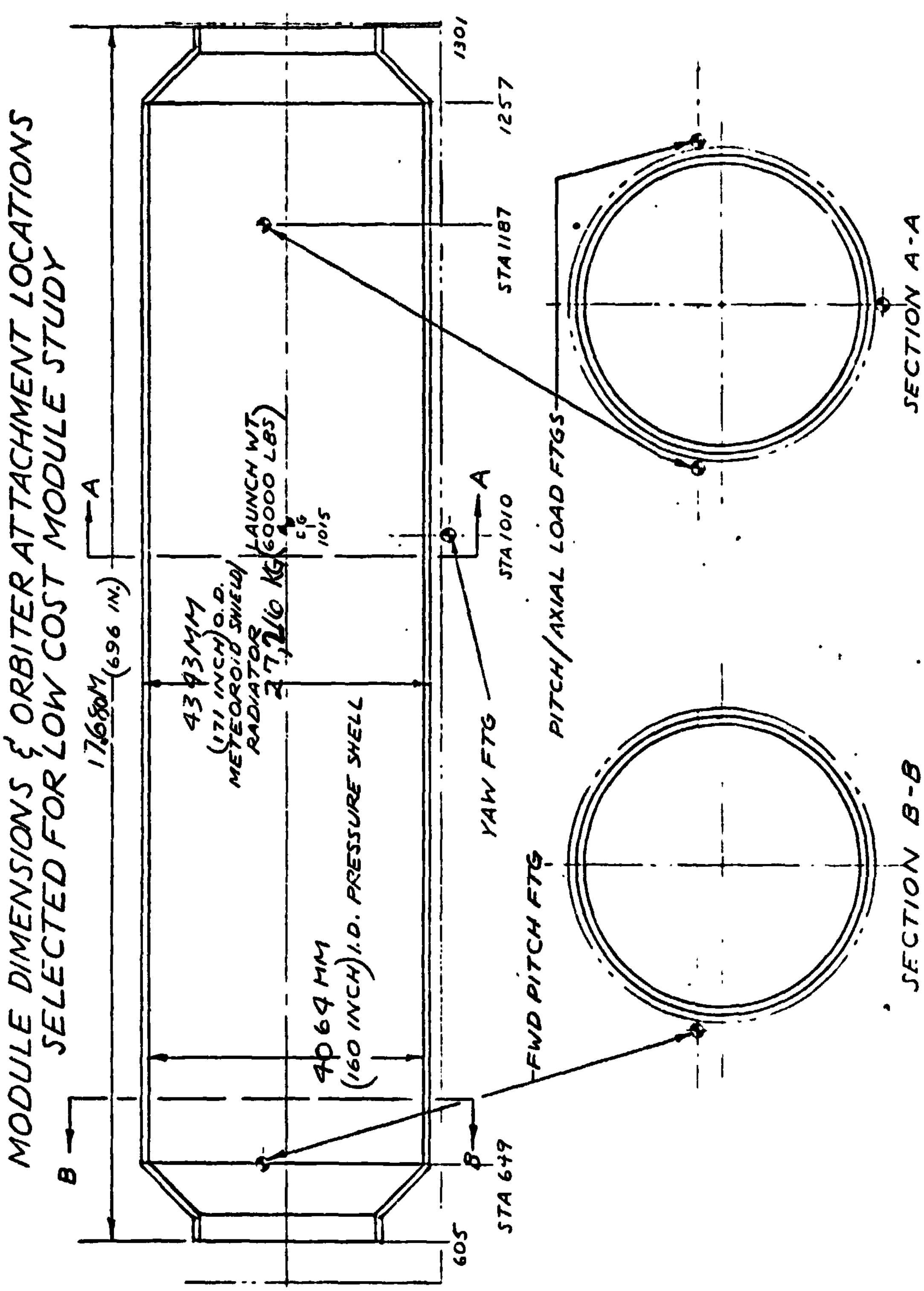
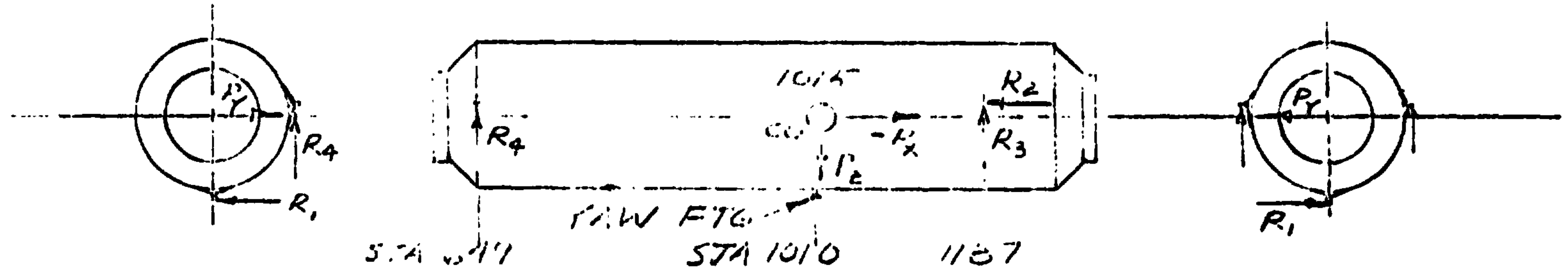

MODULE DIMENSIONS & ORBITER ATTACHMENT LOCATIONS
SELECTED FOR LOW COST MODULE STUDY
17680M (696 IN.)
4343MM (171 INCH) O.D. METEOROID SHIELD/RADIATOR
4064 MM (160 INCH) I.D. PRESSURE SHELL
LAUNCH WT. 27,216 KG (60000 LBS)
CG 1015
A
B
STA 649
STA 1010
STA 1187
605
1257
1301
YAW FTG
FWD PITCH FTG
PITCH/AXIAL LOAD FTGS
SECTION A-A
SECTION B-B

FIG 1

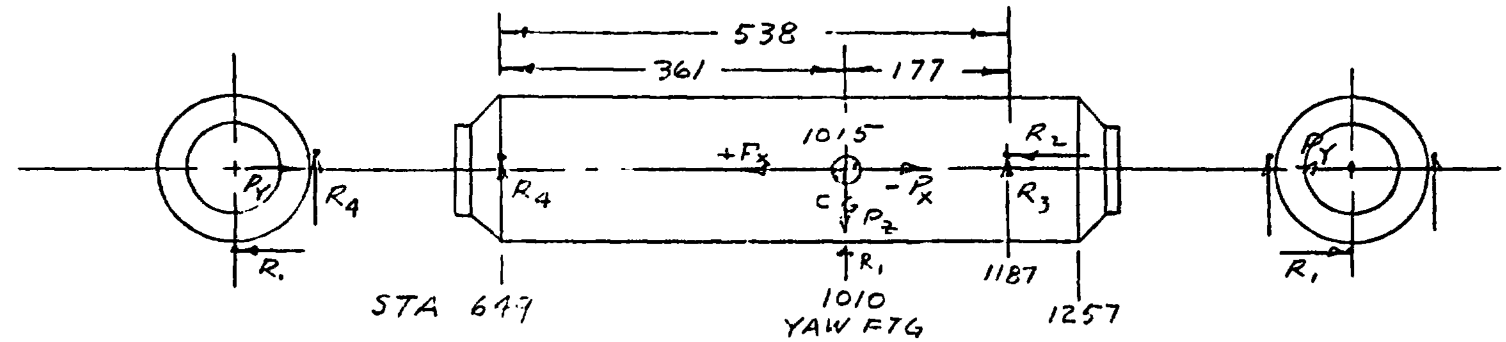


CONDITION	LINEAR G			APPLIED LOAD N			LIMIT REACTIONS N			
	X	Y	Z	P_X	P_Y	P_Z	R_1	R_2	R_3	R_4
LIFT-OFF	-2.9	±1.0	±1.5	-713,752	±266880	±400,320	266,880	394,093	411049	151828
HIGH Q BOOST	-2.0	±.5	±.6	-533760	±133440	±160128	133440	270463	180811	66560
BOOST MAX L.F.	-3.3	±.2	-.75	-330704	±53376	±200160	53376	441795	171510	88751
ENTRY-PITCH	+.94	0	+2.25	+250867	0	+515142	0	125434	397030	202326
ENTRY-YAW	+.67	±1.11	+1.0	+178810	±296237	+266880	29[illegible]37	97402	329401	92452
LANDING	+.89	±.45	+2.42	+237523	±120096	+645850	120096	122004	493225	218659
CRASH	+5.12	±.853	+2.56	1,3[illegible],426	±227649	+683213	227649*	[illegible]360*	587065*	260306*

NOTE
ORBITER ANGULAR RATES AND MODULE
DYNAMIC RESPONSE ARE NEGLECTED

* ULTIMATE REACTIONS

TABLE 1 (METRIC UNITS)



$R_1 = P_Y$ $\quad R_2 = \frac{P_X}{2} + \frac{5P_Y}{188}$ $\quad R_3 = \frac{361 P_Z}{2(538)} + \frac{95 P_Y}{188} + \frac{R_4}{2} - \frac{14 P_X}{2(538)}$ $\quad R_4 = \frac{177 P_Z + 14 P_X}{538}$

$R_2 = .5P_X + .027 P_Y$ $\quad R_3 = .665 P_Z + .505 P_Y + .013 P_X$ $\quad R_4 = .329 P_Z + .026 P_X$

CONDITION	LINEAR G			APPLIED LOAD			LIMIT REACTIONS LBS			
	X	Y	Z	P_X	P_Y	P_Z	R_1	R_2	R_3	R_4
LIFT-OFF	-2.9	±1.0	±1.5	-174000	±60000	±90000	60000	88600	92412	34134
HIGH Q BOOST	-2.0	±.5	±.6	-120000	±30000	±36000	30000	60810	40650	14964
BOOST-MAX LF	-3.3	±.2	-.75	-198000	±12000	±45000	12000	99324	38559	19953
ENTRY-PITCH	+.94	0	+2.23	+56400		+133800		28200	89710	45487
ENTRY-YAW	+.67	±1.11	+1.0	+40200	±66,600	+60000	66600	21898	74056	20785
LANDING	+.89	±.45	+2.42	+53100	±27000	+145200	27000	27429	110887	49157
CRASH	+5.12	±.853	±2.56	307,200	±51180	+153600	51180*	154982*	131984*	58522*

NOTE

ORBITER ANGULAR RATES & MODULE DYNAMIC RESPONSE ARE NEGLECTED.

* ULTIMATE REACTIONS

TABLE 1 (ENGLISH UNITS)

desired damage resistance can be achieved by the use of a sufficiently thick membrane or by the addition of integral ribs to increase the local bending stiffness and impact tolerance.

Critical crack length is a measure of the damage resistance of the pressure shell membrane. An accident which produces a rupture or tear smaller than the critical crack length will result in a leak rather than explosive decompression. Critical crack length is plotted as a function of membrane thickness in Figure 2.

If minimizing the pressure shell cost has primary importance and the pressure shell weight is secondary, the wall thickness of the optimum monocoque cylinder will be the thickness required at the longitudinal welds. The weld thickness selected for Spacelab is 4 mm (0.157 in). If this thickness is used for the low-cost module monocoque cylinder, the resulting critical crack length, as shown in Figure 2, is 74.2 cm (29.2 in) and the monocoque cylinder weight is 2,179 (4,803 lb).

With the single pitch fitting forward and the yaw fitting located at the keel 241 cm (95 in) from the centerline, the torsion in the pressure shell between the yaw fitting at Station 1010 and the X-Z fittings at Station 1187 is

$$T = \frac{(177)\, P_z\, (94)}{538} + 95\, P_y.$$

At liftoff, $T = 9.58 \times 10^5$ nm (8.48×10^6 in-lb).

The maximum beam shear is approximately

$$V = \left[\left(\frac{361\, P_z + 14\, P_x}{538}\right)^2 + P_y^{\,2}\right]^{1/2}$$

at liftoff V = 88,399 lbs and the maximum shear flow $q = V/(\pi R) + T/(2\pi R^2)$ = 986 n/cm (352 + 211 = 563 lb/in).

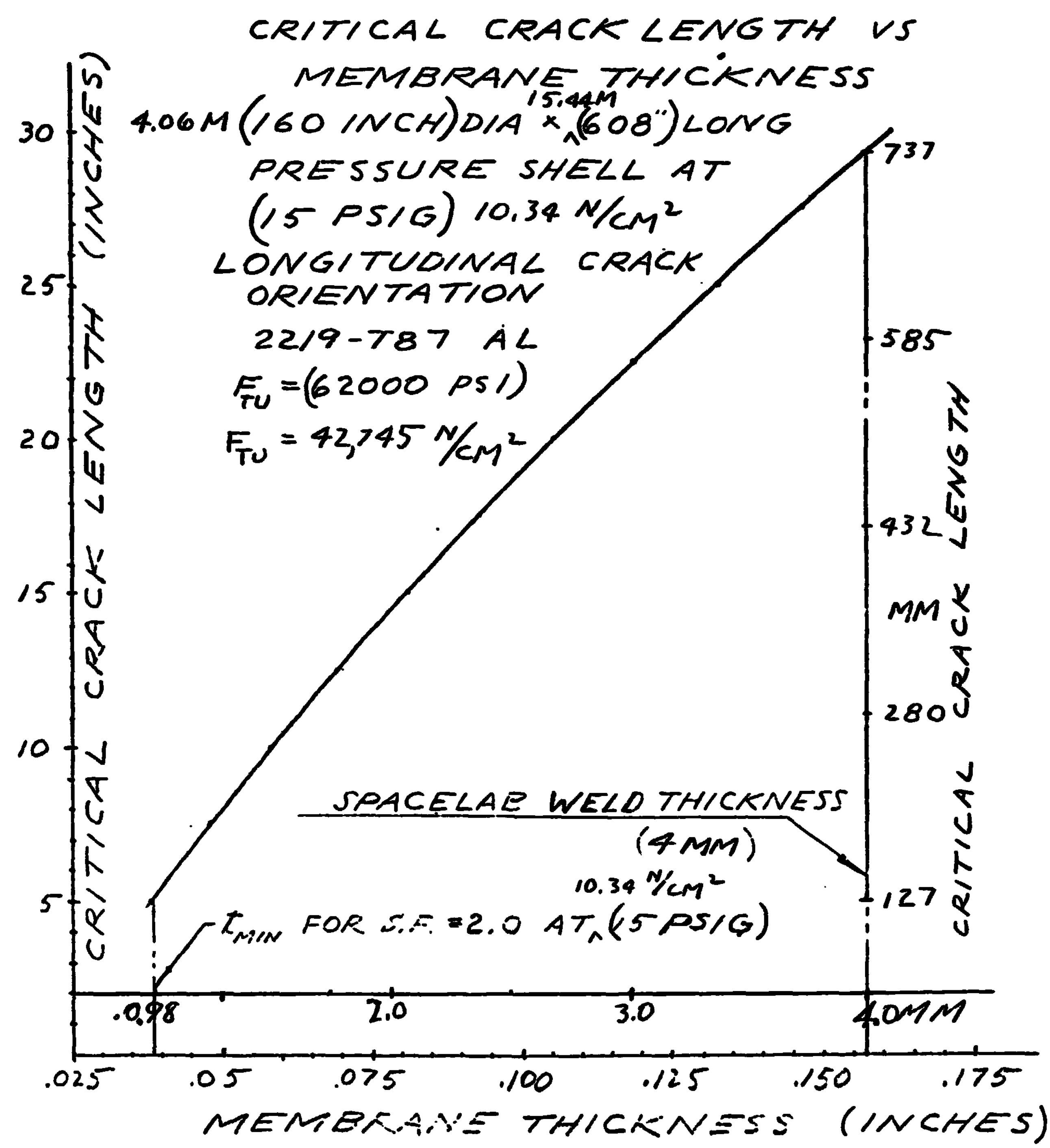

CRITICAL CRACK LENGTH VS MEMBRANE THICKNESS
4.06M (160 INCH) DIA × 15.44M (608") LONG
PRESSURE SHELL AT
(15 PSIG) 10.34 N/CM²
LONGITUDINAL CRACK ORIENTATION
2219-T87 AL
F_TU = (62000 PSI)
F_TU = 42,745 N/CM²
SPACELAB WELD THICKNESS
(4MM)
10.34 N/CM²
t_MIN FOR S.F. = 2.0 AT 10.34 N/CM² (15 PSIG)
CRITICAL CRACK LENGTH (INCHES)
30
25
20
15
10
5
CRITICAL CRACK LENGTH
MM
737
585
432
280
127
.098
2.0
3.0
4.0MM
.025
.05
.075
.100
.125
.150
.175
MEMBRANE THICKNESS (INCHES)

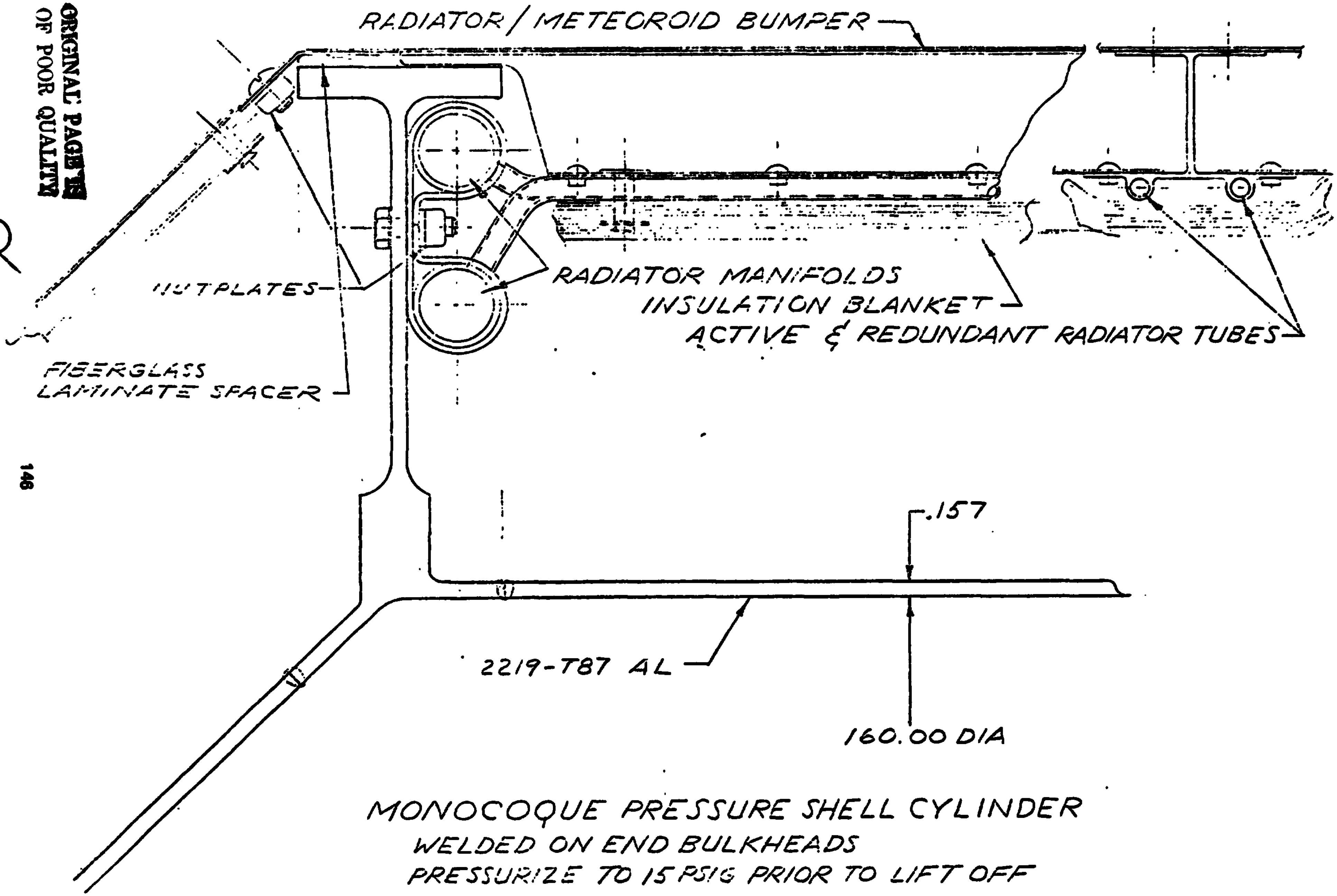
FIG 2

From the Theory of Elastic Stability, by Timoshenko and Gere, Second Edition, 1961, page 507, the critical shear flow for a 13.67m (538 in) long cylinder with 4 mm (0.157 in) wall thickness, under pure torsion is 187 lb/in. Since this is below the applied shear flow at liftoff from torsion alone, the unpressurized monocoque cylinder will buckle under the combined compression, bending, and torsion at liftoff.

The lowest cost approach for stabilizing the monocoque cylinder against buckling is to pressurize it to the relief valve setting prior to liftoff. It requires about 240 kg (530 lb) of added atmosphere to pressurize to 10.34 n/cm^2 (15 psig) before launch, but since 90% of this added weight will have vented by 15 km (50,000 ft), it has a very small effect on the useful payload. Since the module will normally have stored gas provisions for one or more repressurizations on orbit, this stored gas can be used to maintain 10 n/cm^2 (15 psig) in the event of an abort reentry if the repressurization system is modified to maintain a specified pressure differential rather than an absolute pressure in the module.

One option for joining the end closure and the monocoque pressure shell cylinder is shown in Figure 3. With the bulkheads welded on as shown, two options remain for installing the internally mounted equipment. One option is to mate all the equipment with its support structure and to install it in the pressure shell as an integrated, completely assembled and checked out unit, prior to welding on the end bulkhead. This option necessitates leaving space for the internal chill bars that are required for the bulkhead weld. An obvious second option with the end bulkhead welded on is to install the internally mounted equipment through the hatch in the end bulkhead. This option may require the use of removable work platforms. With the end bulkheads welded on, the radiator/meteoroid shroud must be installed in two clam-shell sections or be designed with a longitudinal joint that permits springing it open to fit over the end frame.

A bolted joint for joining the end bulkheads and the monocoque pressure shell cylinder is shown in Figure 4. The cost difference between the bolted and welded joints must be weighed against the ease of equipment installation or removal that the bolt on end bulkhead makes possible, as with the Spacelab



MONOCOQUE PRESSURE SHELL CYLINDER
WELDED ON END BULKHEADS
PRESSURIZE TO 15 PSIG PRIOR TO LIFT OFF

LOW COST MODULE STUDY FIG 3

MONOCOQUE PRESSURE SHELL CYLINDER
BOLT ON END BULKHEADS
LOW COST MODULE STUDY

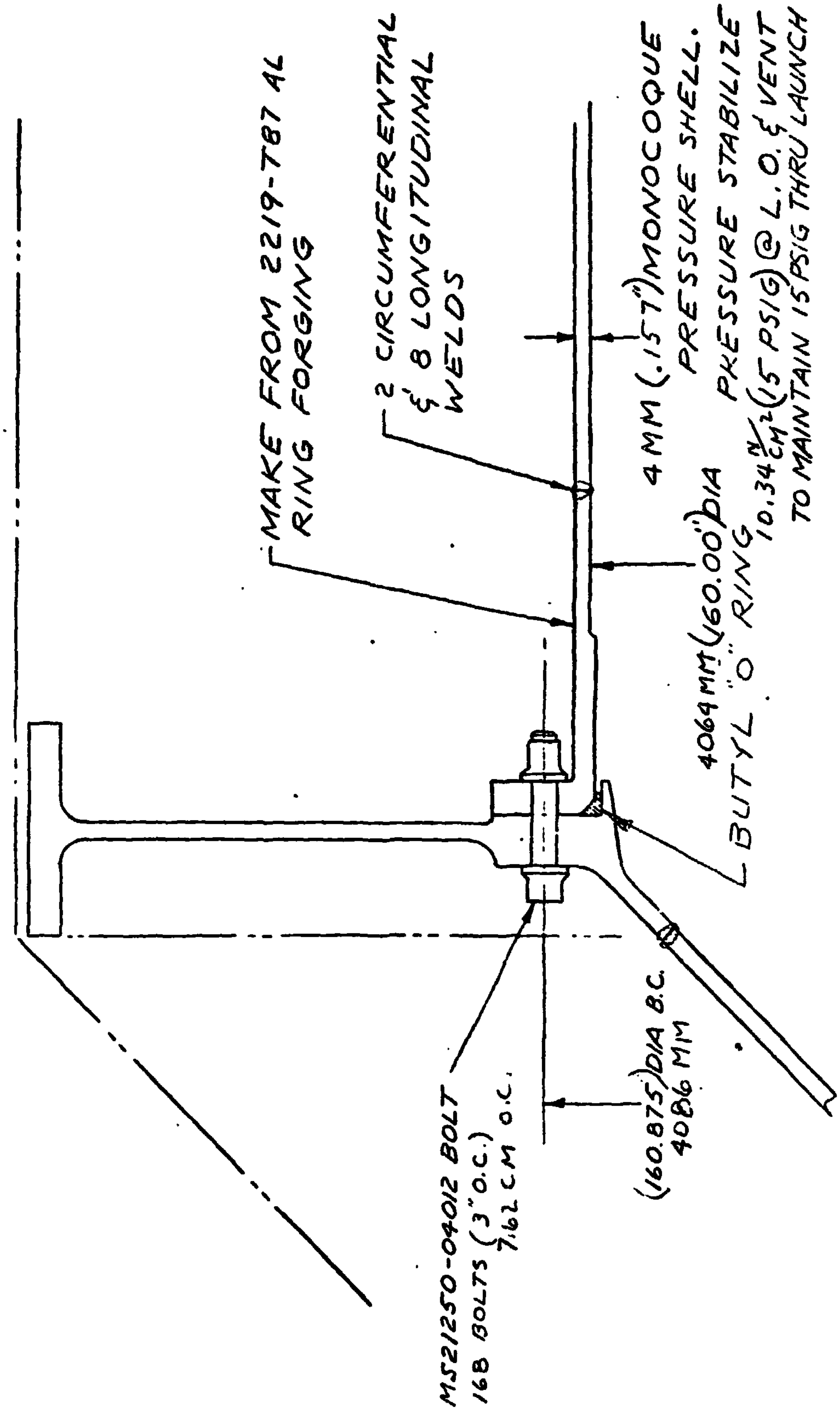


FIG 4

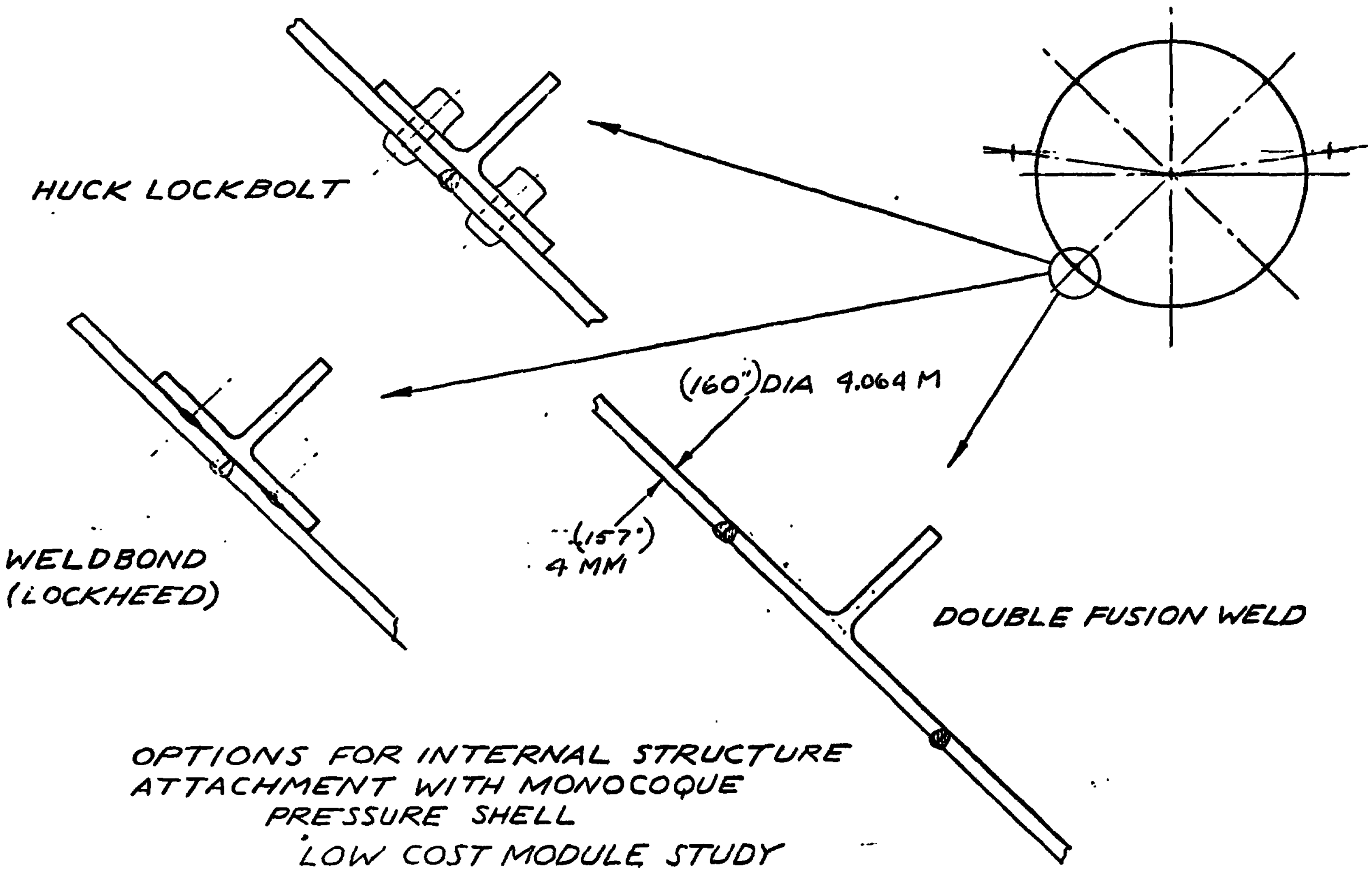
design where ease of changeout and turnaround time are paramount considerations. In the joint design shown, the bolts are installed from outside the pressure shell and an "O" ring seal is used rather than a bead of RTV sealant so that no interior volume need be reserved for making up the joint.

Provisions must be made for distributing inertia loads from internally mounted equipment to the monocoque pressure shell. Some options for attaching four axial ribs for this purpose are shown in Figure 5.

Provisions must also be made for distributing the launch inertia loads from the Orbiter interface fittings at Station 1187 and the yaw fitting at Station 1010 to the monocoque pressure shell. This requires external frames at Stations 1010 and 1187, and two external longerons extending between them. Two options for attaching the frame at Station 1187 are shown in Figure 6. If huck lockbolts are used, they must be pressure-tight through installation with the proper interference fit, or sealed with an RTV sealant or equivalent so that they remain pressure-tight after exposure to the shock and vibration loading that accompanies Shuttle launch. Comparison of the cost of the modified monocoque cylinder with integrally machined alternatives designed to satisfy the modular Space Station mission requirements is the purpose of this study. The combination radiator and meteoroid shroud, though an important feature of Space Station modules, is not included in this low cost module study beyond recognizing its existence and the need to provide for its installation. The radiator and meteoroid shroud design configuration that is optimum for the monocoque pressure shell cylinder will also be optimum for the integrally machined isogrid, lending justification to this study simplification.

MONOCOQUE CYLINDER

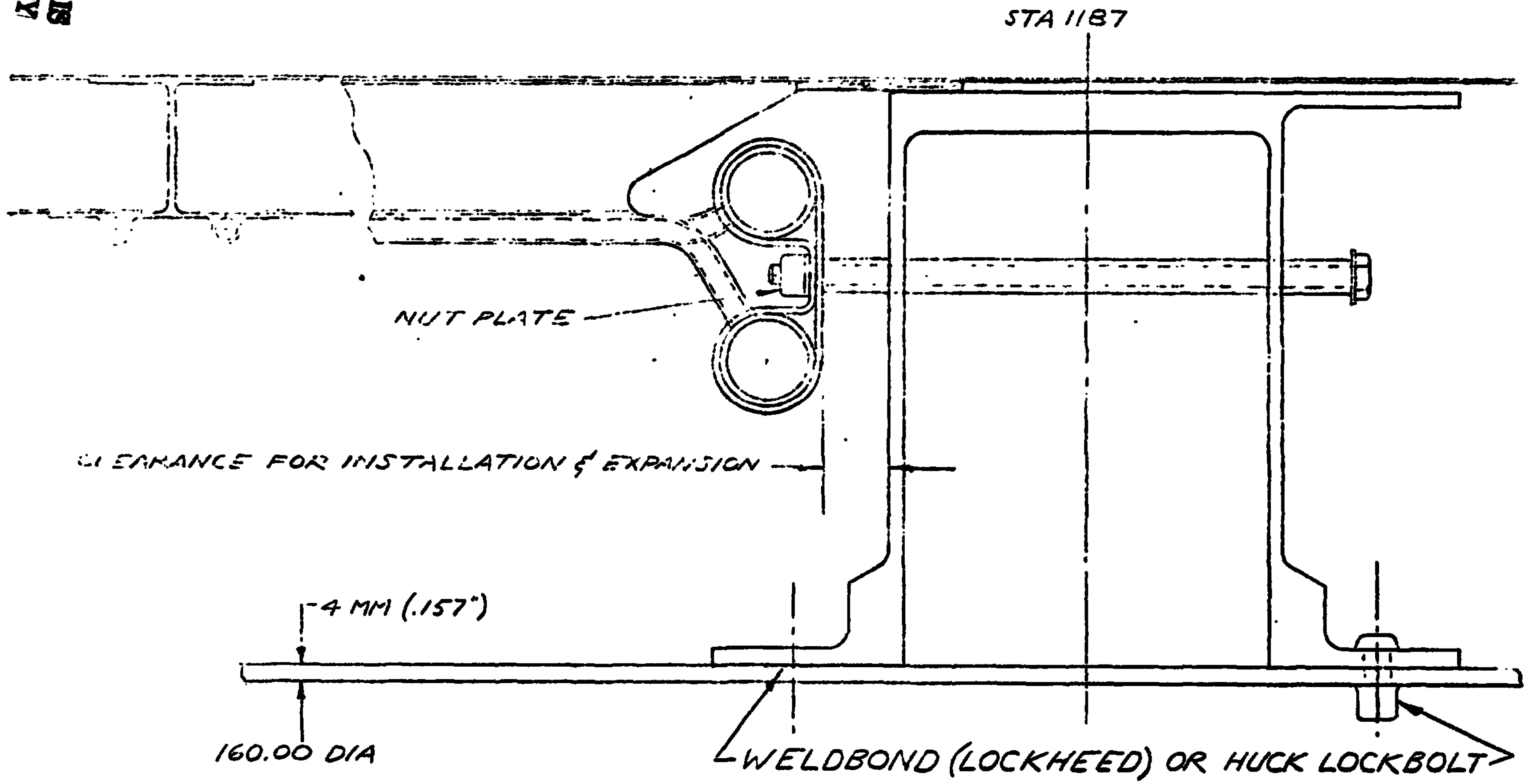
The monocoque cylinder configuration selected as a result of the advance manufacturing cost estimates for the options shown in Figure 5 and 6 is shown in Figure 7. Frames fabricated from stretch-formed extrusions (shown in View F) are huckbolted to the skin to distribute the pitch and yaw launch loads. Extruded tee-section longerons are fusion-welded to the skin as shown in View B to distribute the axial launch inertia loads from internal



OPTIONS FOR INTERNAL STRUCTURE ATTACHMENT WITH MONOCOQUE PRESSURE SHELL
LOW COST MODULE STUDY

FIG 5

MONOCOQUE PRESSURE SHELL CYLINDER
FRAME ATTACHMENT OPTIONS



LOW COST MODULE STUDY
FIG 6

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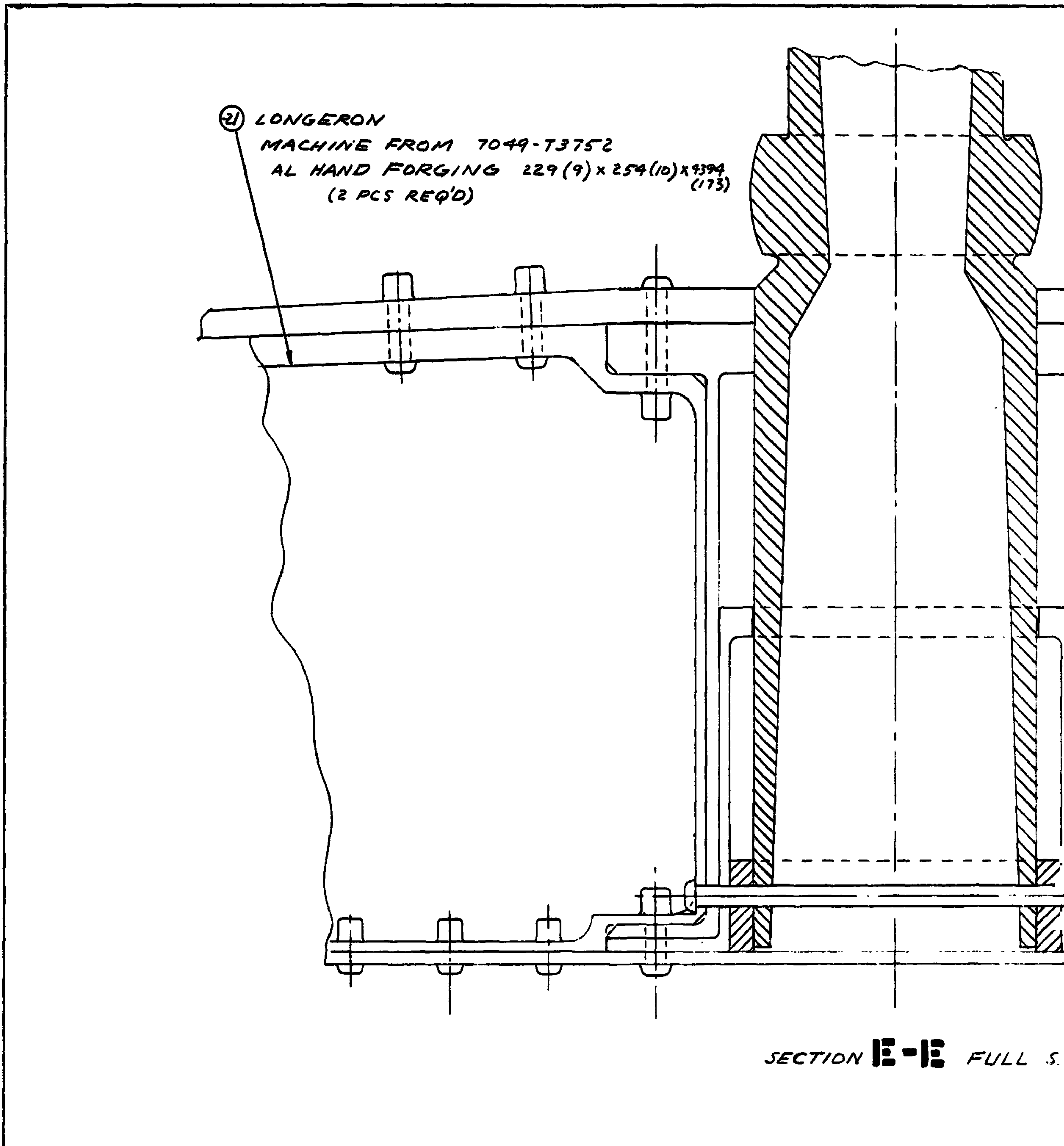
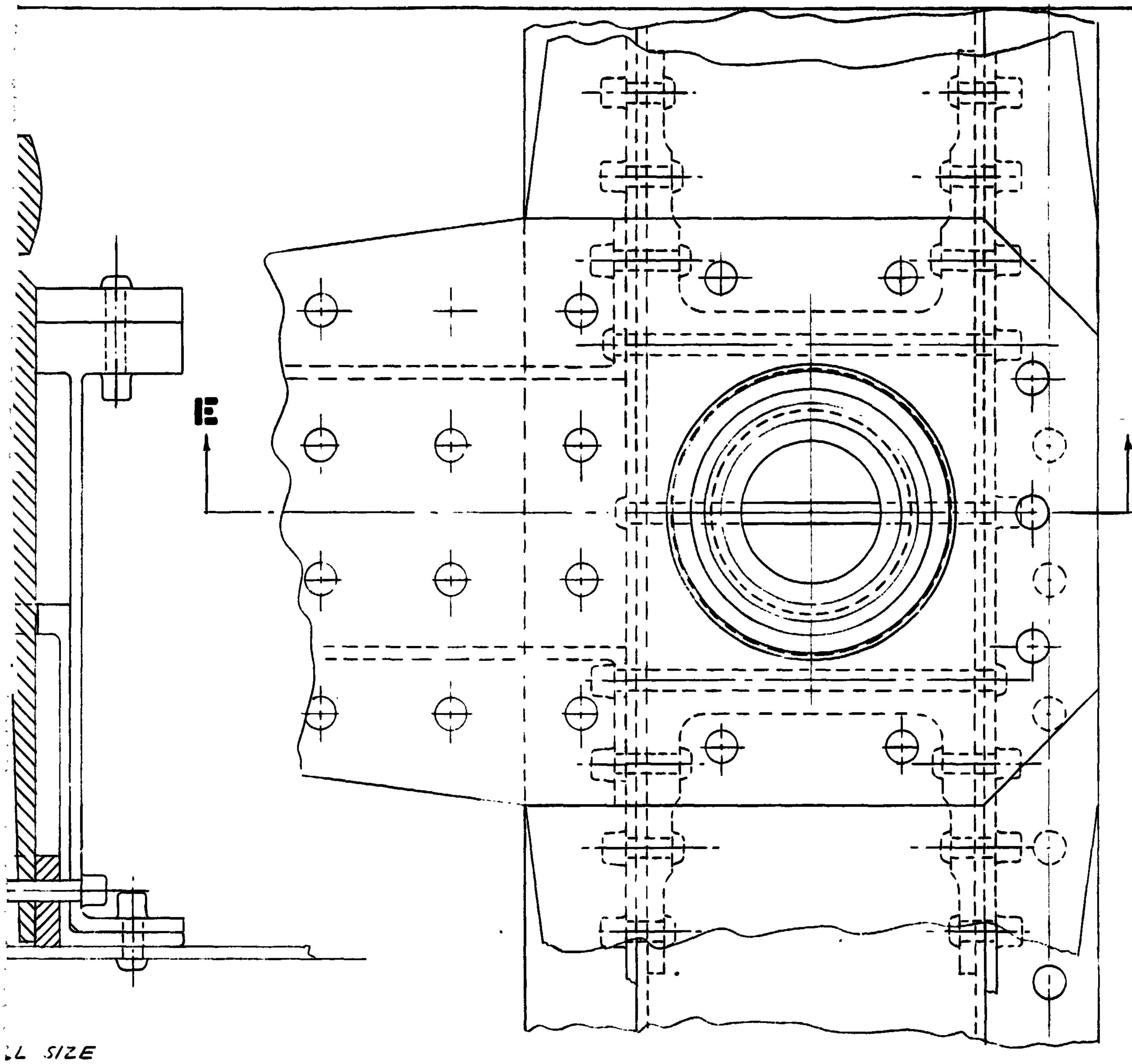
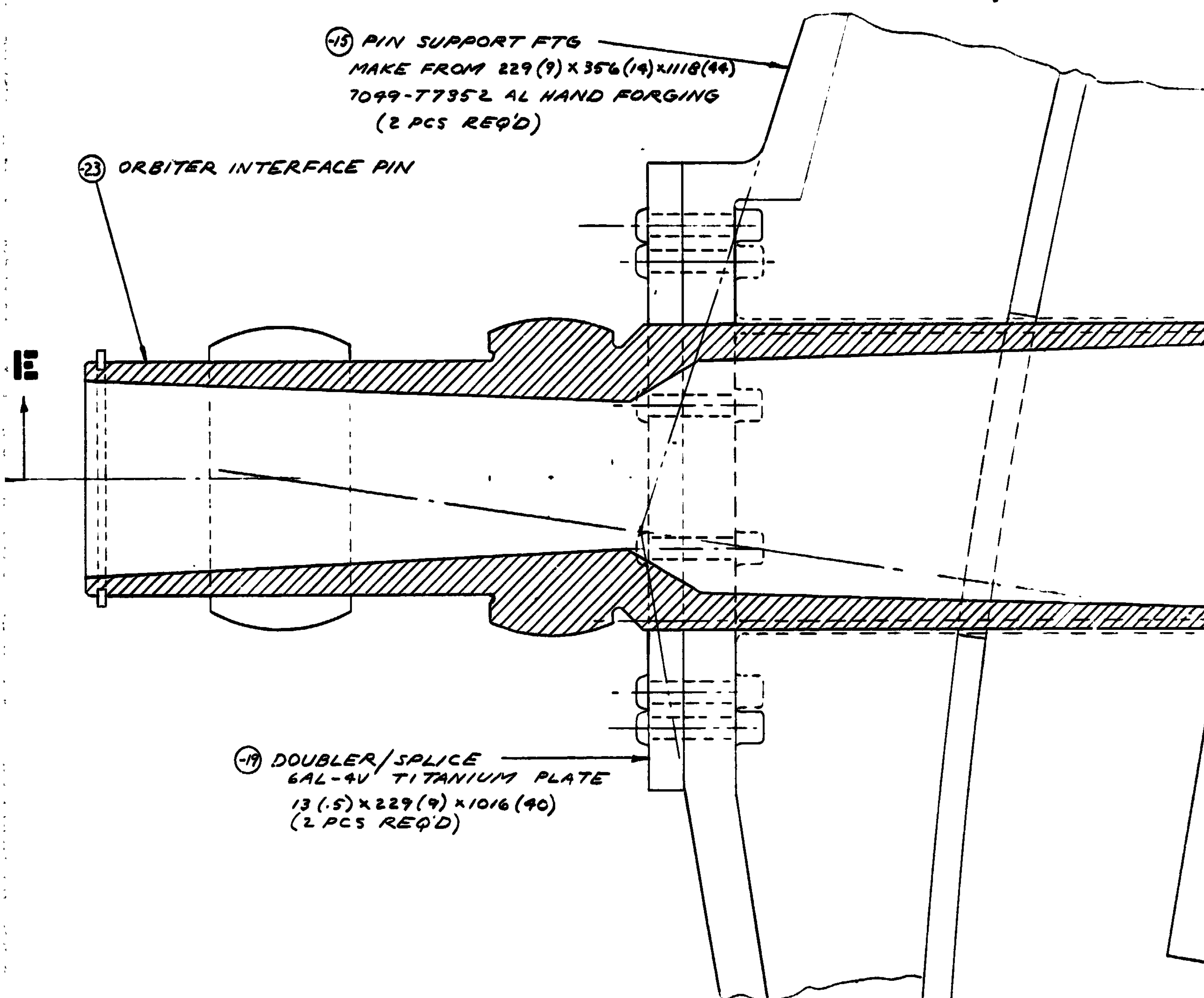


FOLDOUT FRAME

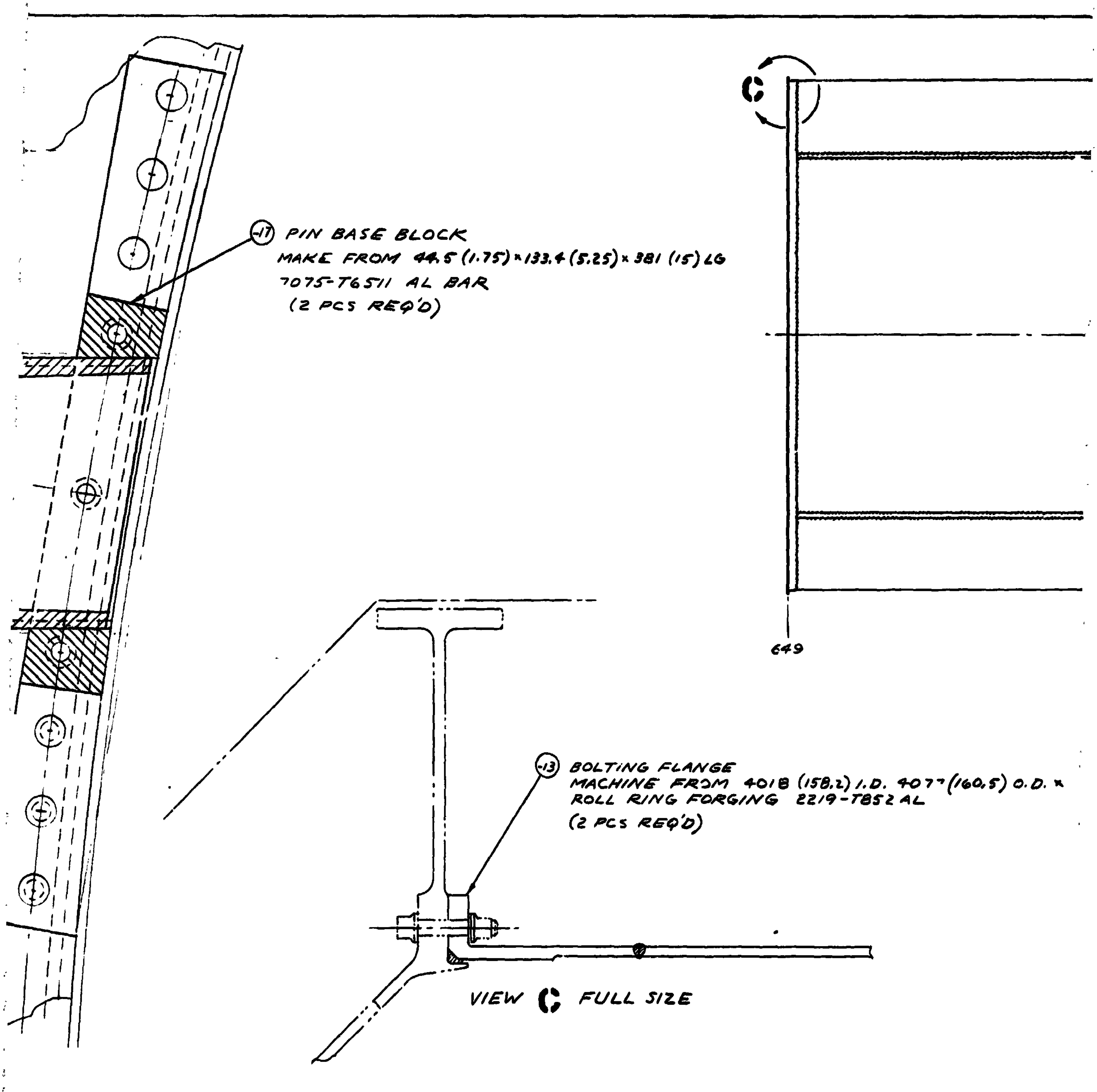


OLDOUT FRAME 2

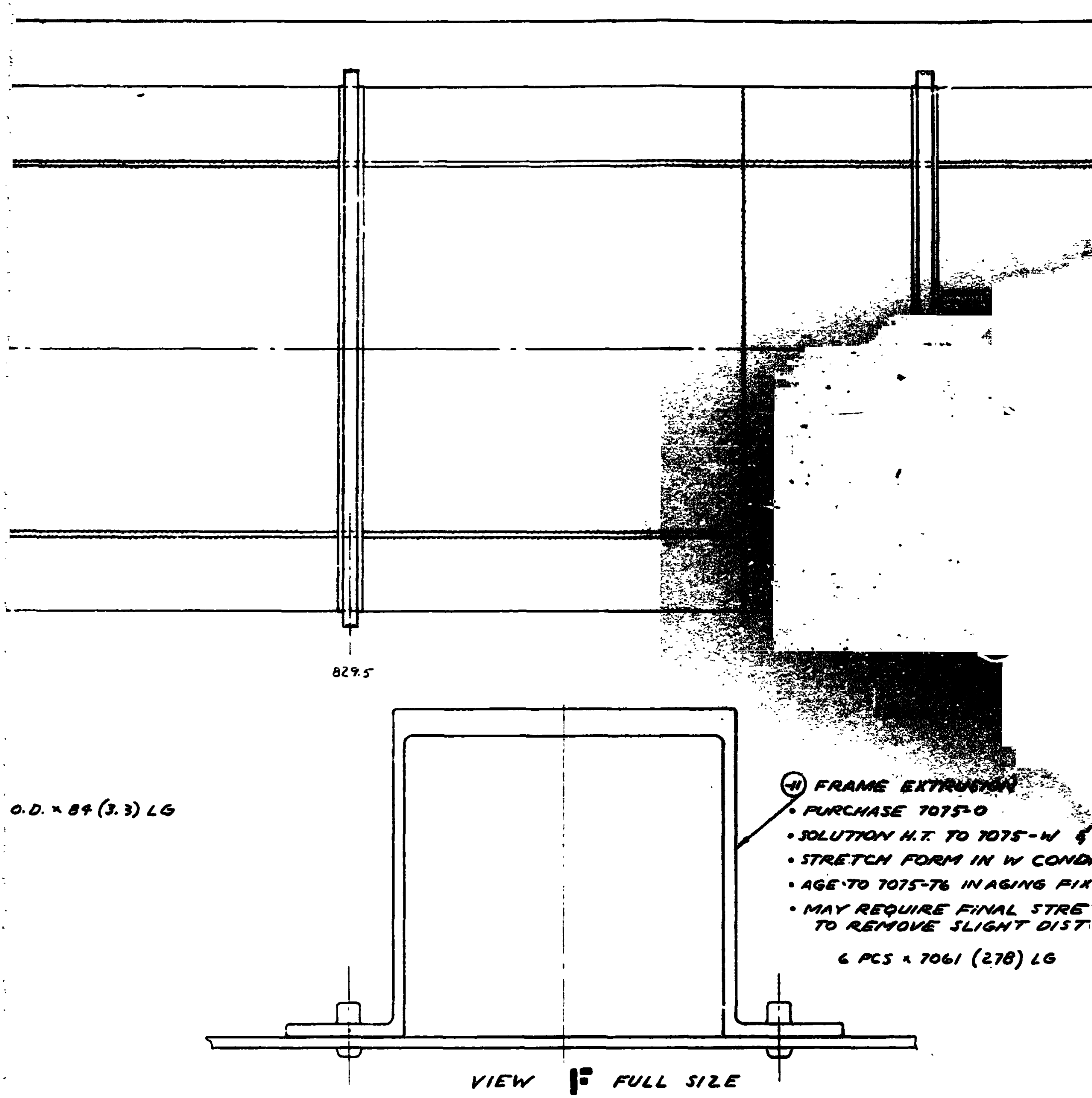


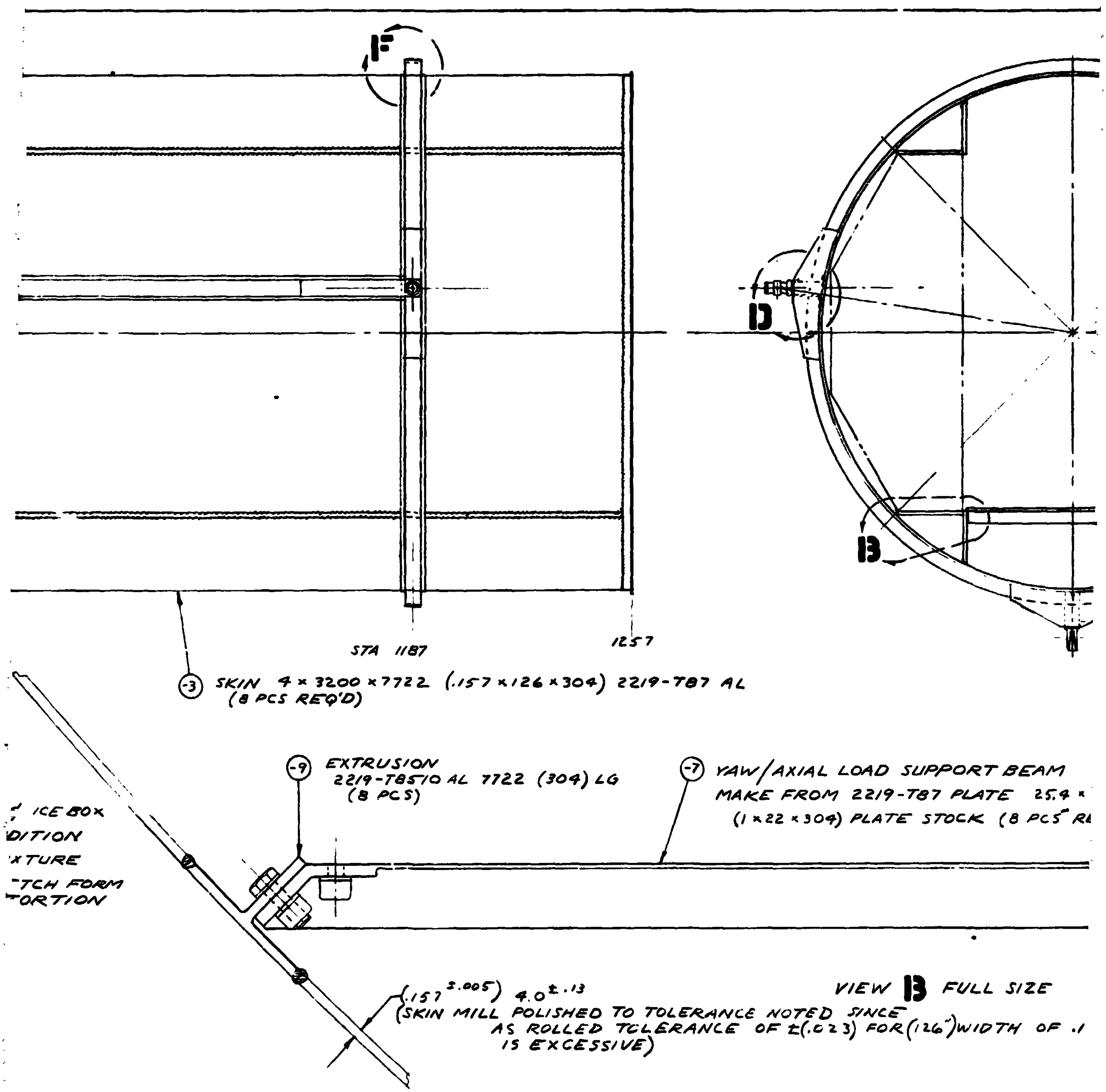
VIEW D FULL SIZE
(SHOWN AS SECTION THRU PIN ℄ FOR CLARITY)

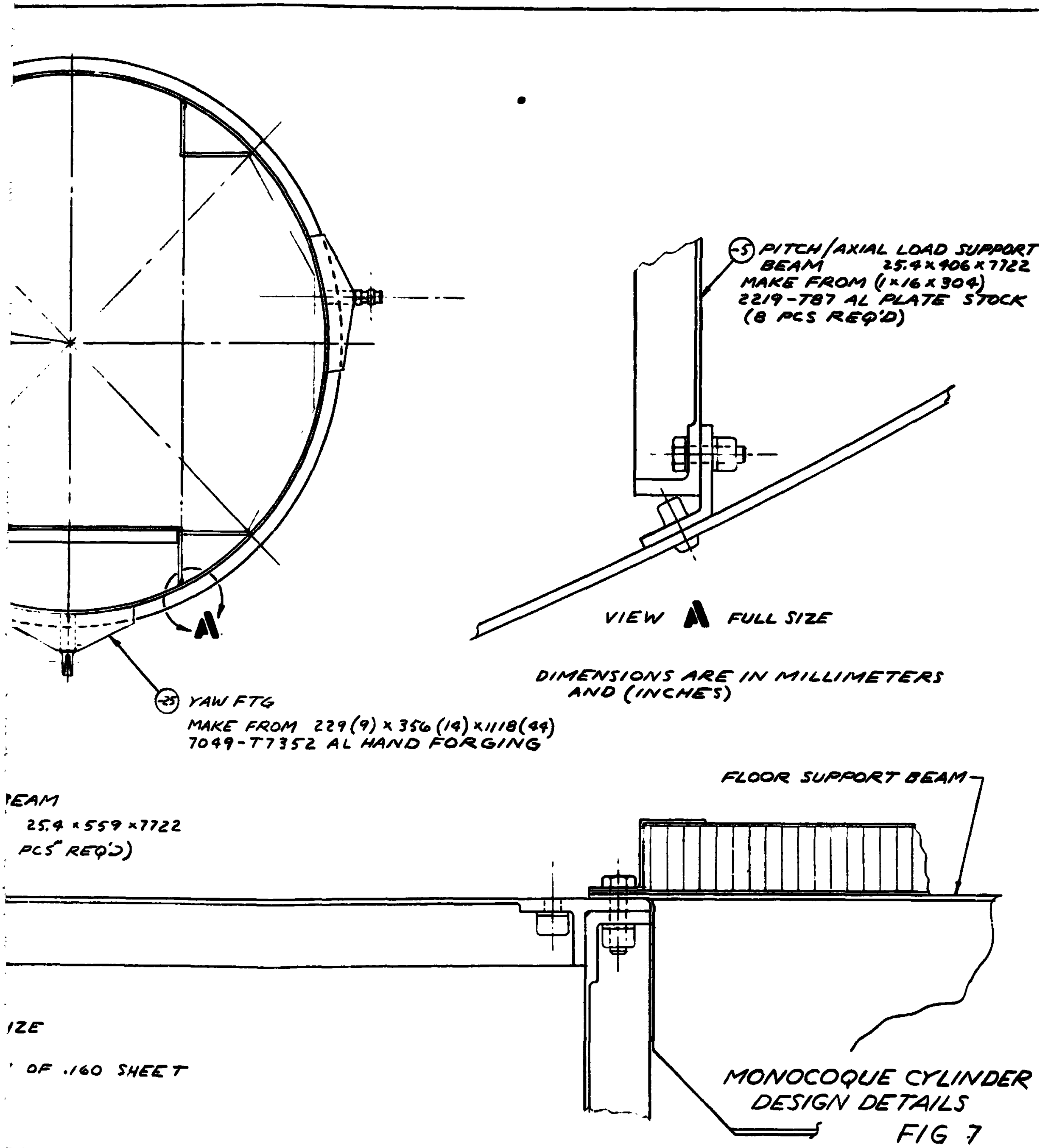
FOLDOUT FRAME 3



-17 PIN BASE BLOCK
MAKE FROM 44.5 (1.75) × 133.4 (5.25) × 381 (15) LG
7075-T6511 AL BAR
(2 PCS REQ'D)
C
649
-13 BOLTING FLANGE
MACHINE FROM 4018 (158.2) I.D. 4077 (160.5) O.D. ×
ROLL RING FORGING 2219-T852 AL
(2 PCS REQ'D)
VIEW C FULL SIZE


829.5
O.D. × 84 (3.3) LG
(-11) FRAME EXTRUSION
• PURCHASE 7075-O
• SOLUTION H.T. TO 7075-W
• STRETCH FORM IN W COND
• AGE TO 7075-T6 IN AGING FIX
• MAY REQUIRE FINAL STRE
TO REMOVE SLIGHT DIST
6 PCS × 7061 (278) LG
VIEW F FULL SIZE


F
D
B
STA 1187
1257
-3 SKIN 4 × 3200 × 7722 (.157 × 126 × 304) 2219-T87 AL
(8 PCS REQ'D)
-9 EXTRUSION
2219-T8510 AL 7722 (304) LG
(8 PCS)
-7 YAW/AXIAL LOAD SUPPORT BEAM
MAKE FROM 2219-T87 PLATE 25.4 ×
(1 × 22 × 304) PLATE STOCK (8 PCS
ICE BOX
DITION
XTURE
TCH FORM
ORTION
(.157 ±.005) 4.0 ±.13
(SKIN MILL POLISHED TO TOLERANCE NOTED SINCE
AS ROLLED TOLERANCE OF ±(.023) FOR (126") WIDTH OF .1
IS EXCESSIVE)
VIEW B FULL SIZE



MONOCOQUE CYLINDER DESIGN DETAILS

FIG 7

1-25-77

FOLDOUT FRAME 7

equipment. Four beams (shown in View A) support the Z-direction loads between frames. Four beams (shown in View B) support the Y-direction loads between frames.

The manufacturing cost trade shows the weld-on end bulkhead option costs \$15,520 per module less than the bolt-on option. However, the bolt on option is shown in View C because it is anticipated that the small additional cost of the bolt-on provisions will be considerably more than offset by the reduction in the cost of equipment installation that the improved access provides.

Provisions for mounting the support pins which interface the Orbiter at Station 1187 are shown in View D and Section E.

Eight sheets are joined by four longitudinal welds and one circumferential weld to make the monocoque cylinder. The resultant sheet size is approximately 320 cm (126 in) wide by 772 cm (304 in) long. At this width, the tolerance on the as-rolled sheet is ±0.058 cm (0.023 in) in the thickness range 0.358 to 0.437 cm (0.141 in to 0.172 in) and ± 0.066 cm (0.026 in) in the thickness range (0.173 in to 0.203 in). The standard gage thickness nearest the 4 mm (0.157 in) thickness desired at the weld is 0.406 cm (0.160 in), but the ±0.058 cm (0.023 in) tolerance for this gage and width results in a possible 0.348 cm (0.137 in) thickness at the weld which is below that dictated by the fracture mechanics analysis completed for Spacelab. Several options remain. The next standard gage 4.83 ±0.66 mm (0.190 ±0.026), can be used in the as-rolled condition, giving a minimum thickness at the weld of 4.17 mm (0.164 in), or 0.190 sheet can be purchased and mill-polished to 0.157 ±0.005 at a cost of about \$500 per sheet. Since the mill-polishing cost of \$4,000 per module produces a weight savings of about 453 kg (1,010 lb), this appears to be the most cost-effective way of accommodating the broad thickness tolerance that standard rolling mill practices require with this premium width sheet. A third alternative is to purchase sheets requiring special rolling-mill practices to reduce the thickness tolerance to ±5%, or 4.06 ±0.2 mm (0.160 ±0.008) for the as-rolled sheet. The cost of special rolling-mill operations for 48 sheets was not compared with the costs of mill polishing, but may represent a viable alternative.

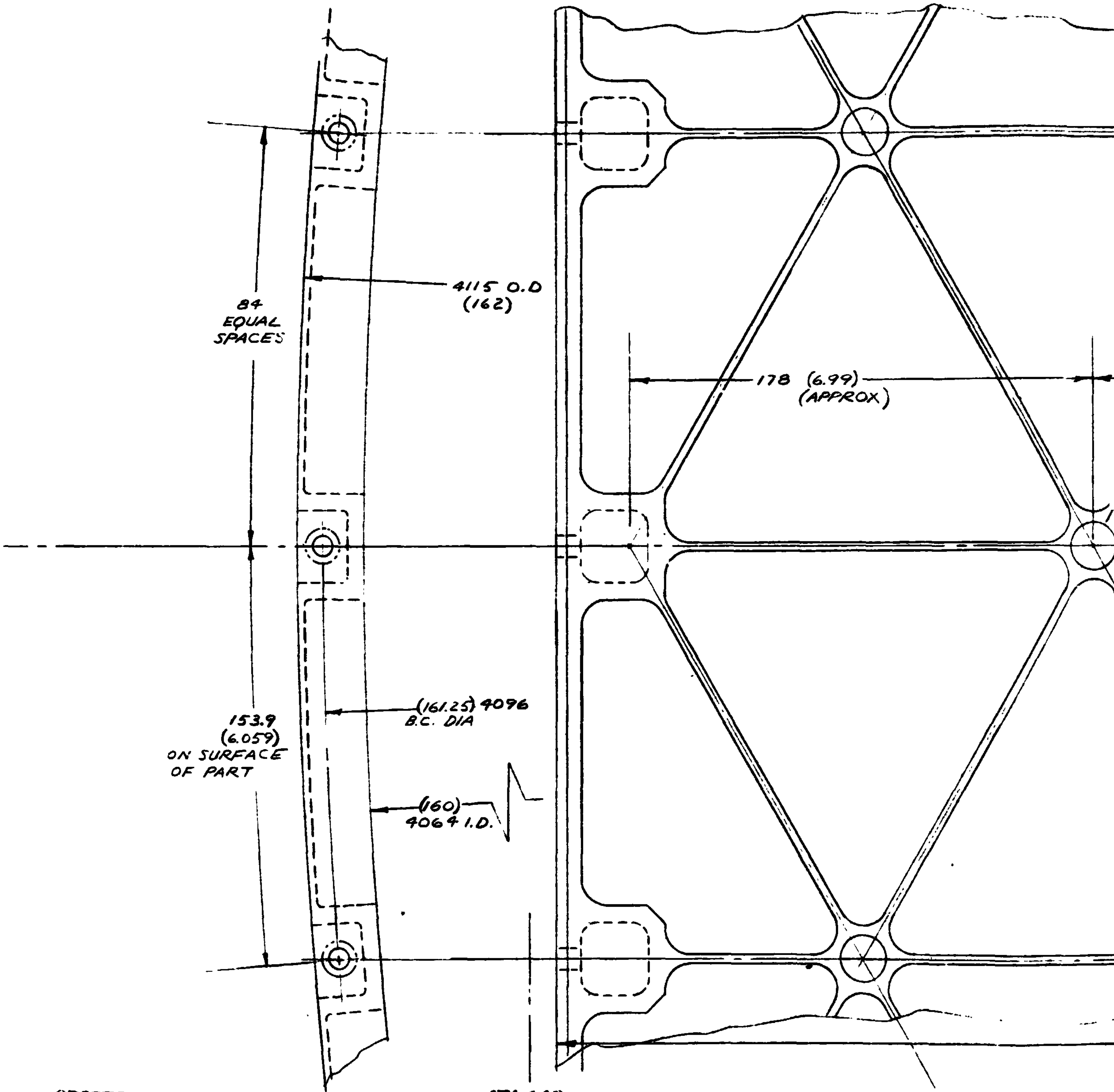
ISOGRID CYLINDER

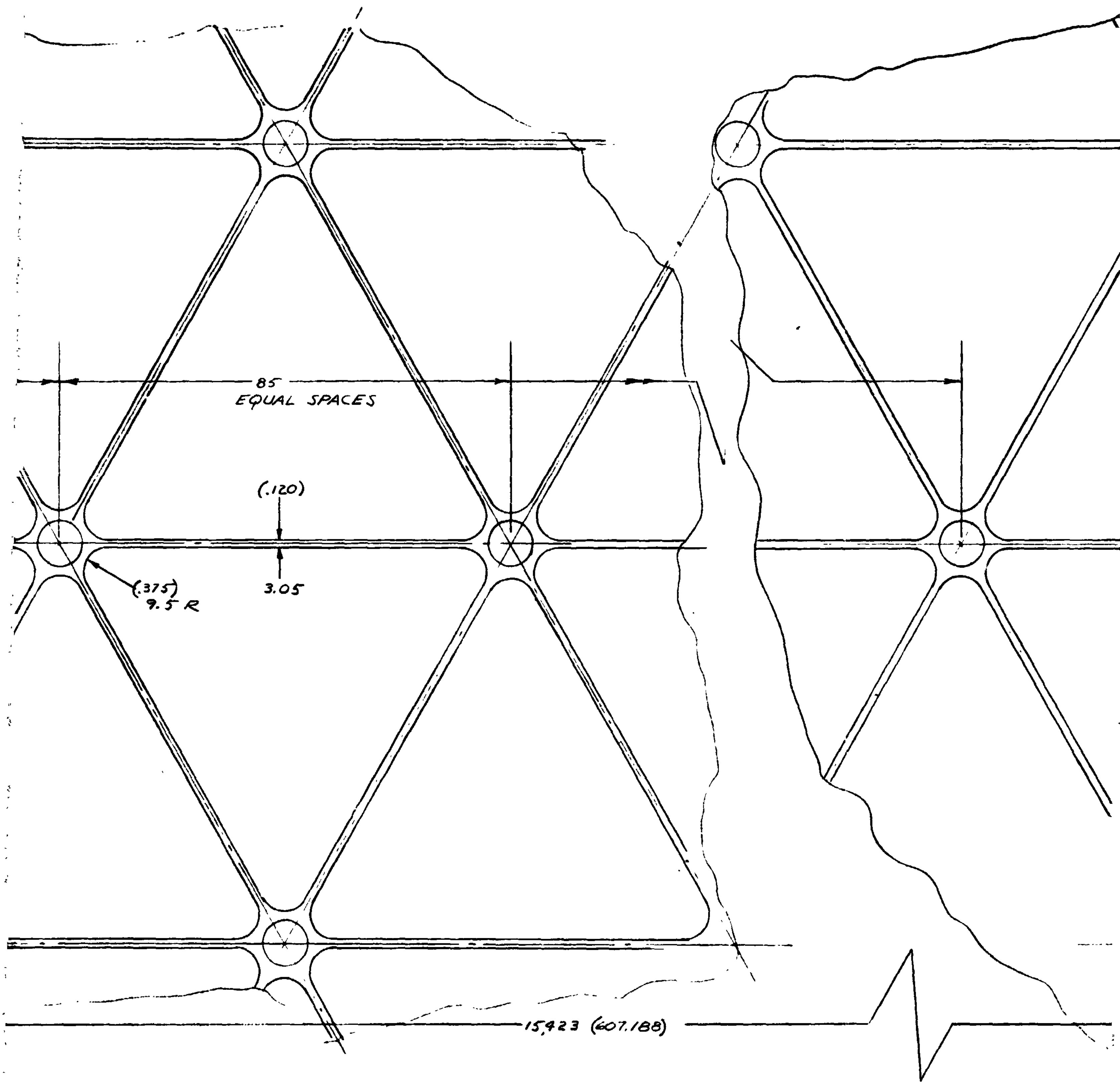
The isogrid cylinder machining details and provisions for mounting in the Orbiter, which were prepared for cost comparison with the monocoque cylinder details, are shown in Figure 8. The launch loads are introduced tangentially into the isogrid shell by the four machined structs shown in View D. The details of the strut-to-cylinder joints are shown in Section C-C. The machining anomalies in the isogrid pattern required to accommodate the tangential strut attachment to the cylinder are shown in View B. The details of the attachment of the struts to the Orbiter interface pin are shown in Section A-A.

The ability of the isogrid cylinder to rapidly distribute concentrated loads which are tangentially introduced eliminates the requirements for frames and longerons which are replaced by the tangential struts. Elimination of frames and longerons, and care in the design of the strut-to-cylinder joint, eliminate huckbolt penetrations of the pressure shell and the attendant potential for low leakage which might be of some significance over the life of the module.

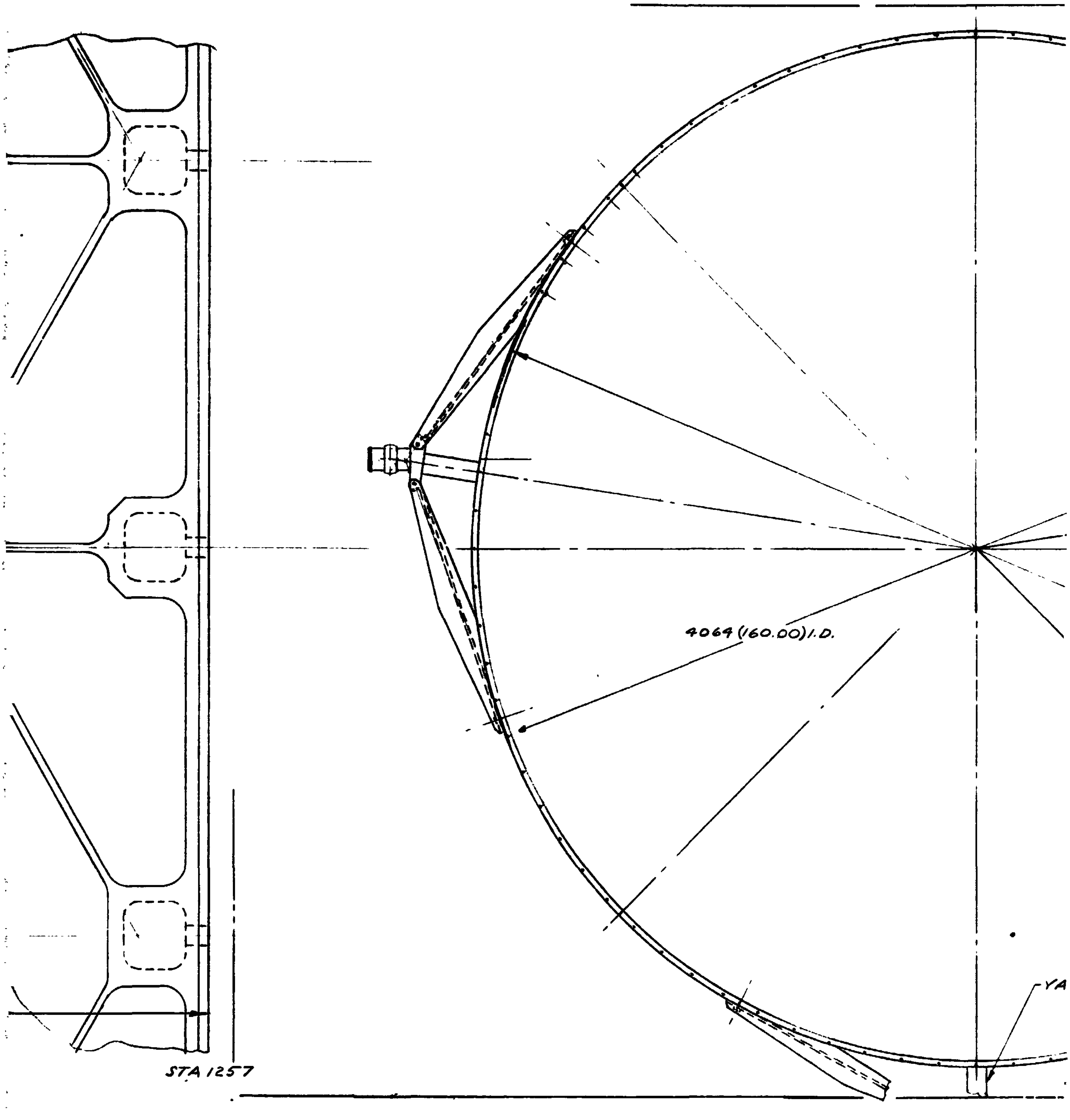
External and internal ribs are viable alternative options for the isogrid cylinder skins. The external option, shown in Figure 9, simplifies machining of the integral bolting flange. The internal option, shown in Figure 10, requires that the skin be turned over to machine the bolt-well pockets. However, the isogrid nodes, which are used for equipment support, are visible from the inside with the internal rib option, and MDAC brake-forming experience with internal ribs is considerably more extensive than with external ribs. For these reasons, the internal rib isogrid configuration was selected for cost comparison with the monocoque cylinder design.

Provisions for the attachment of secondary structure to the isogrid cylinder are shown in Figure 11. As indicated, 280 inserts are installed (140 each side) to provide a standardized array of attach points for joining the secondary structure to the module. With this arrangement, the racks and floor, together with the complete complement of equipment they contain, can be assembled outside the pressure shell on a piece of GSE and installed using that GSE as an integrated, checked out unit; or, alternatively, each rack with its equipment


4115 O.D
(162)
84
EQUAL
SPACES
178 (6.99)
(APPROX)
(161.25) 4096
B.C. DIA
153.9
(6.059)
ON SURFACE
OF PART
(160)
4064 I.D.
STA 649



FOLDOUT FRAME 2



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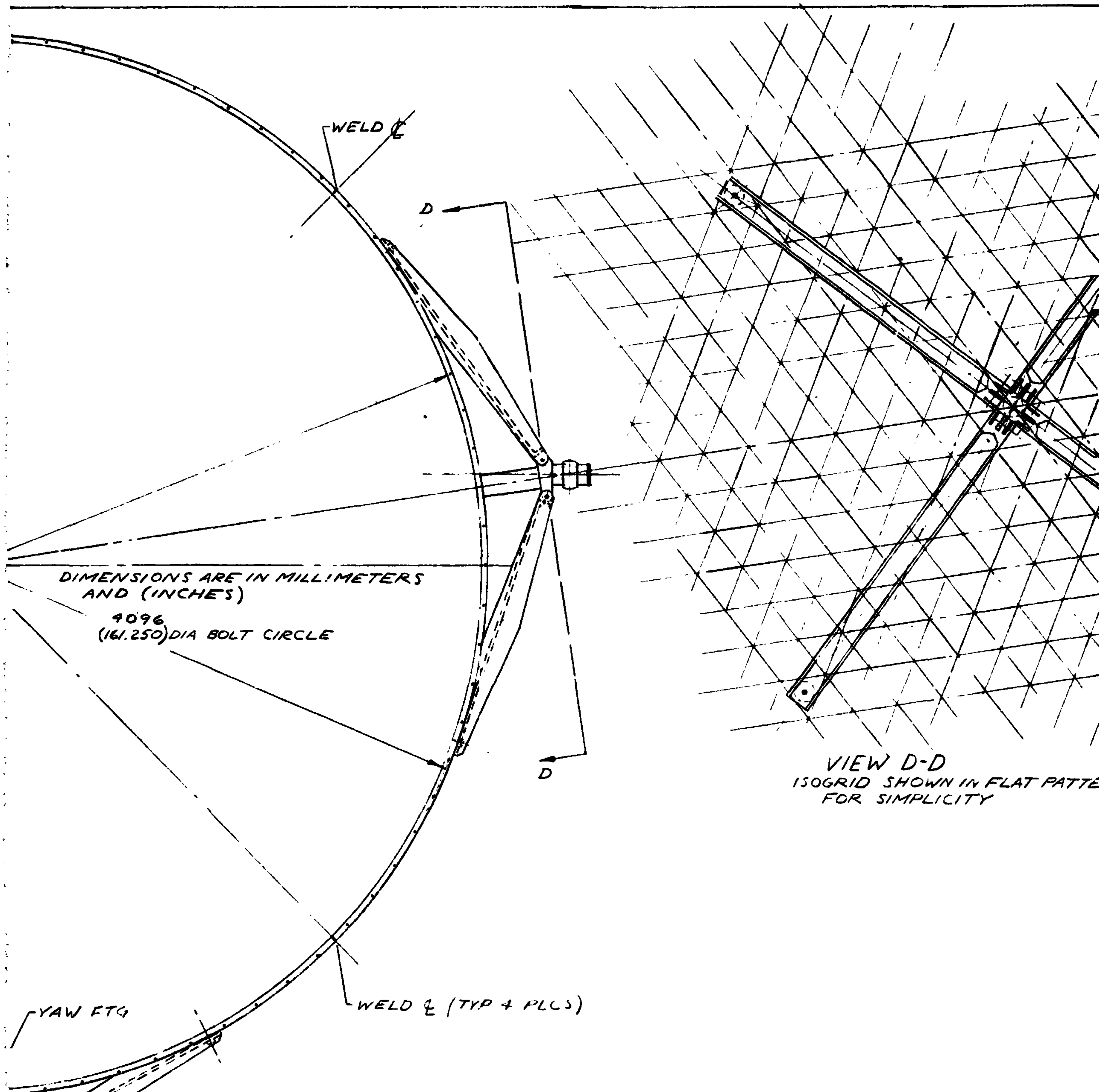
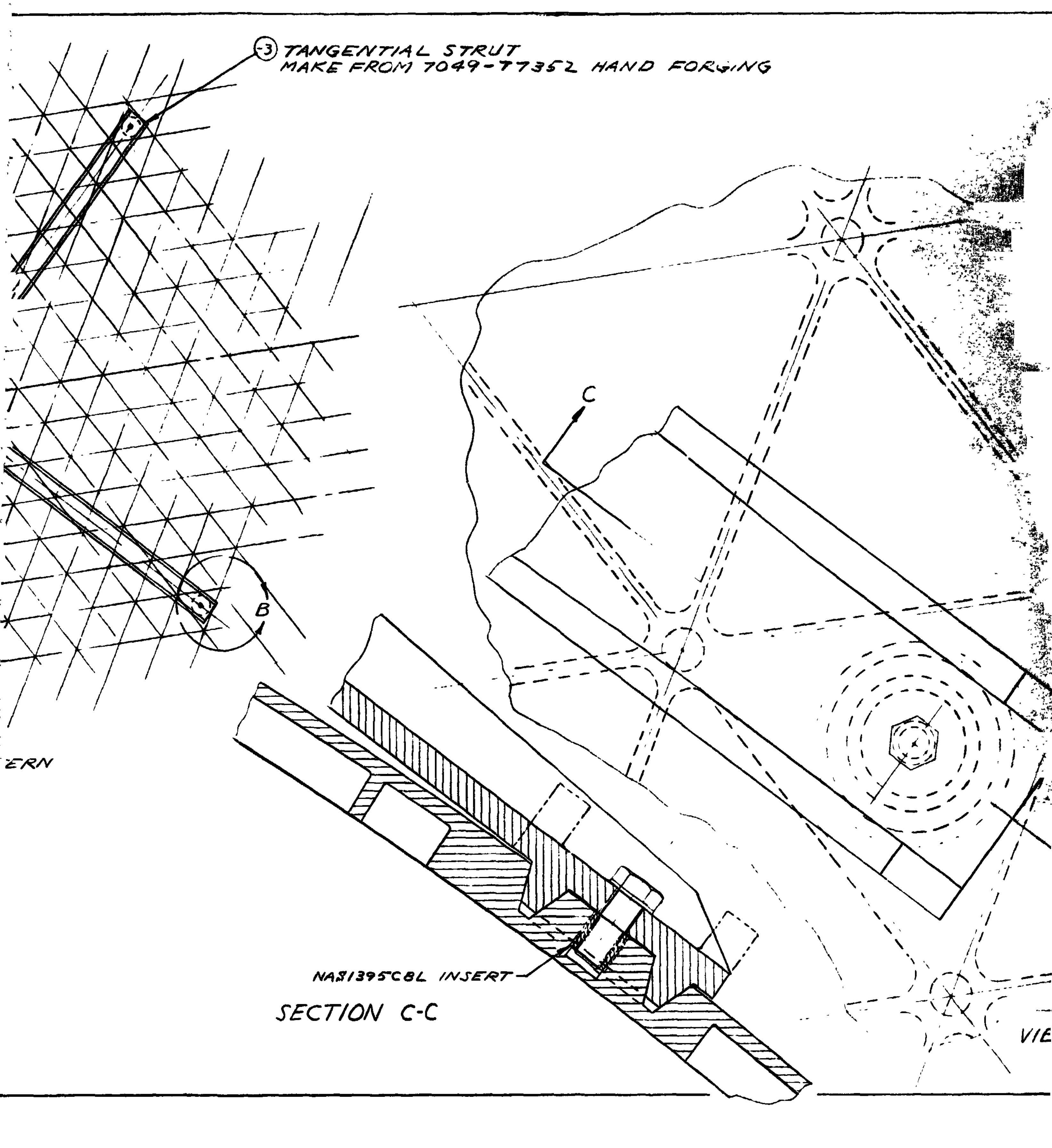
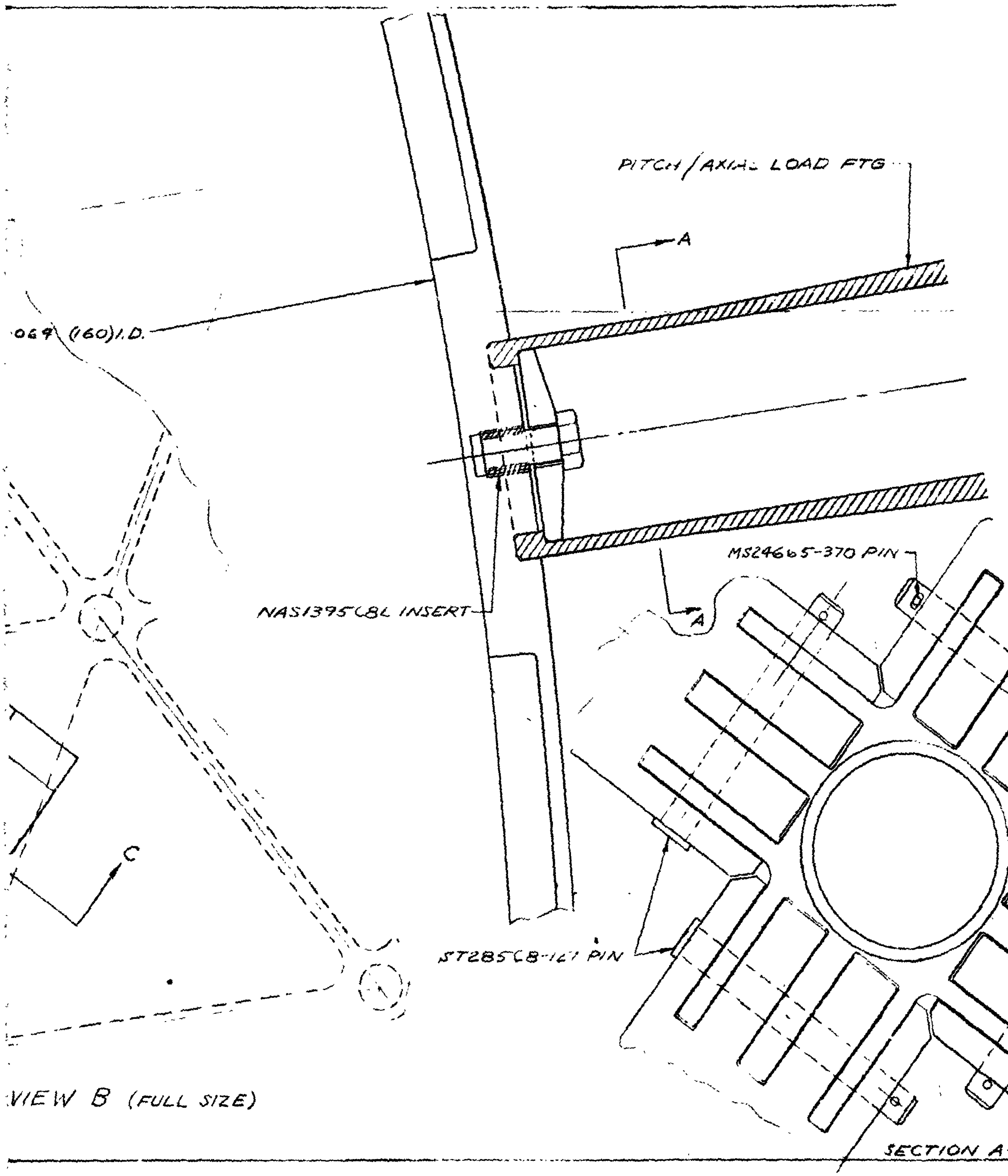


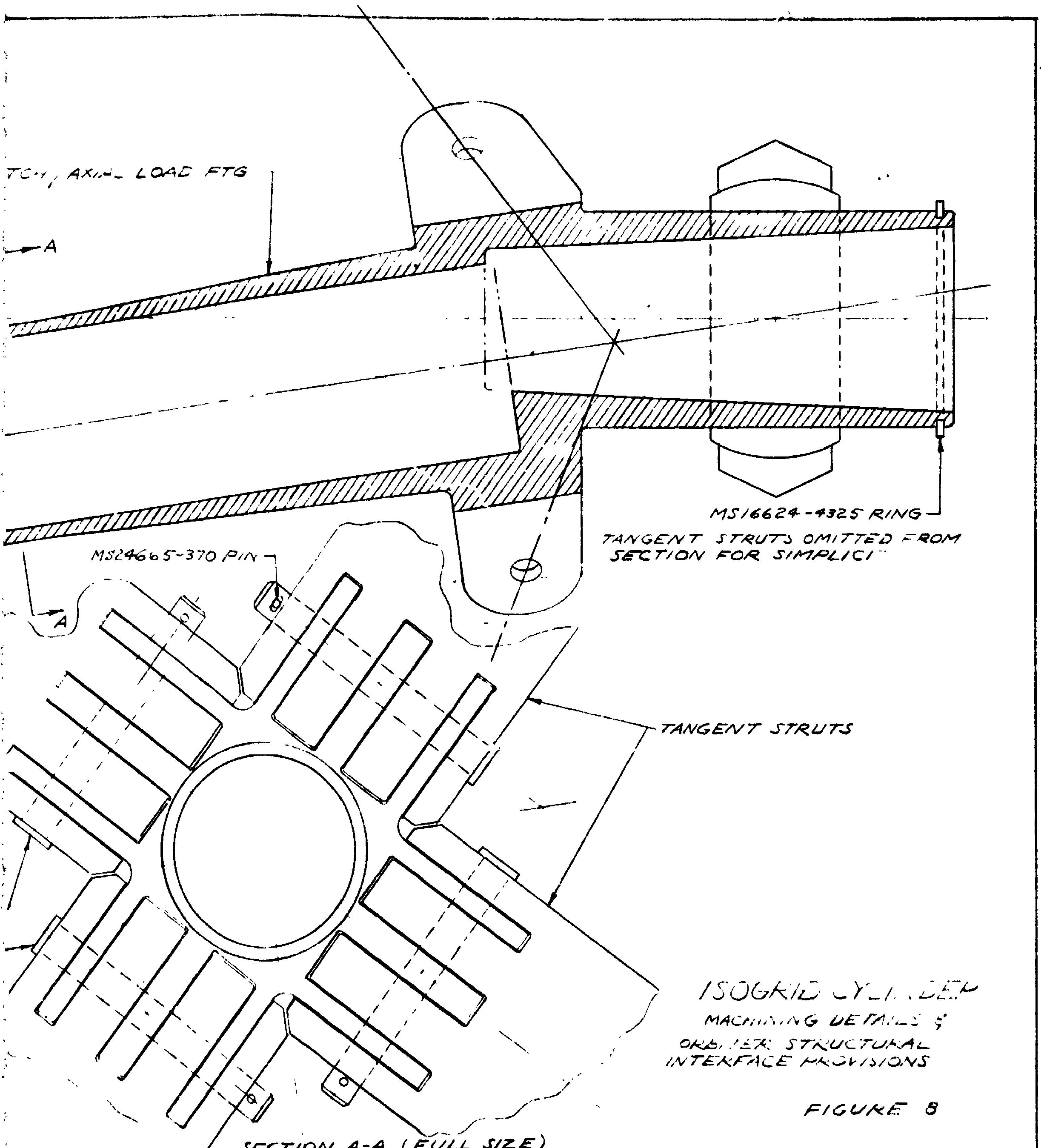
FOLDOUT FRAME 4



3 TANGENTIAL STRUT
MAKE FROM 7049-T7352 HAND FORGING
C
B
ERN
NAS1395C8L INSERT
SECTION C-C
VIE



FOLDOUT FRAME 6



ISOGRID CYLINDER
MACHINING DETAILS &
ORBITER STRUCTURAL
INTERFACE PROVISIONS

FIGURE 8

HARTMANN 1-6-77

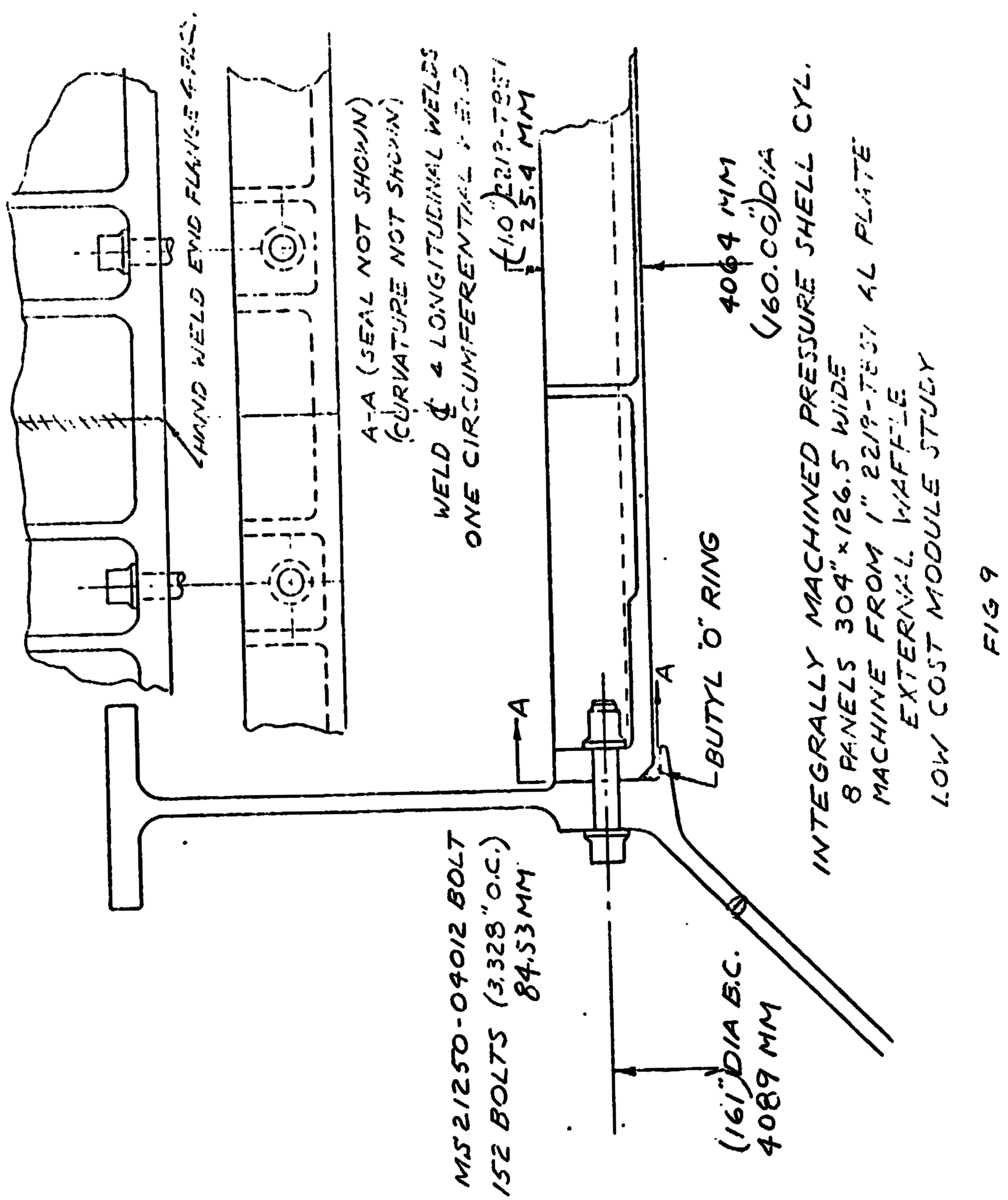


FIG 9

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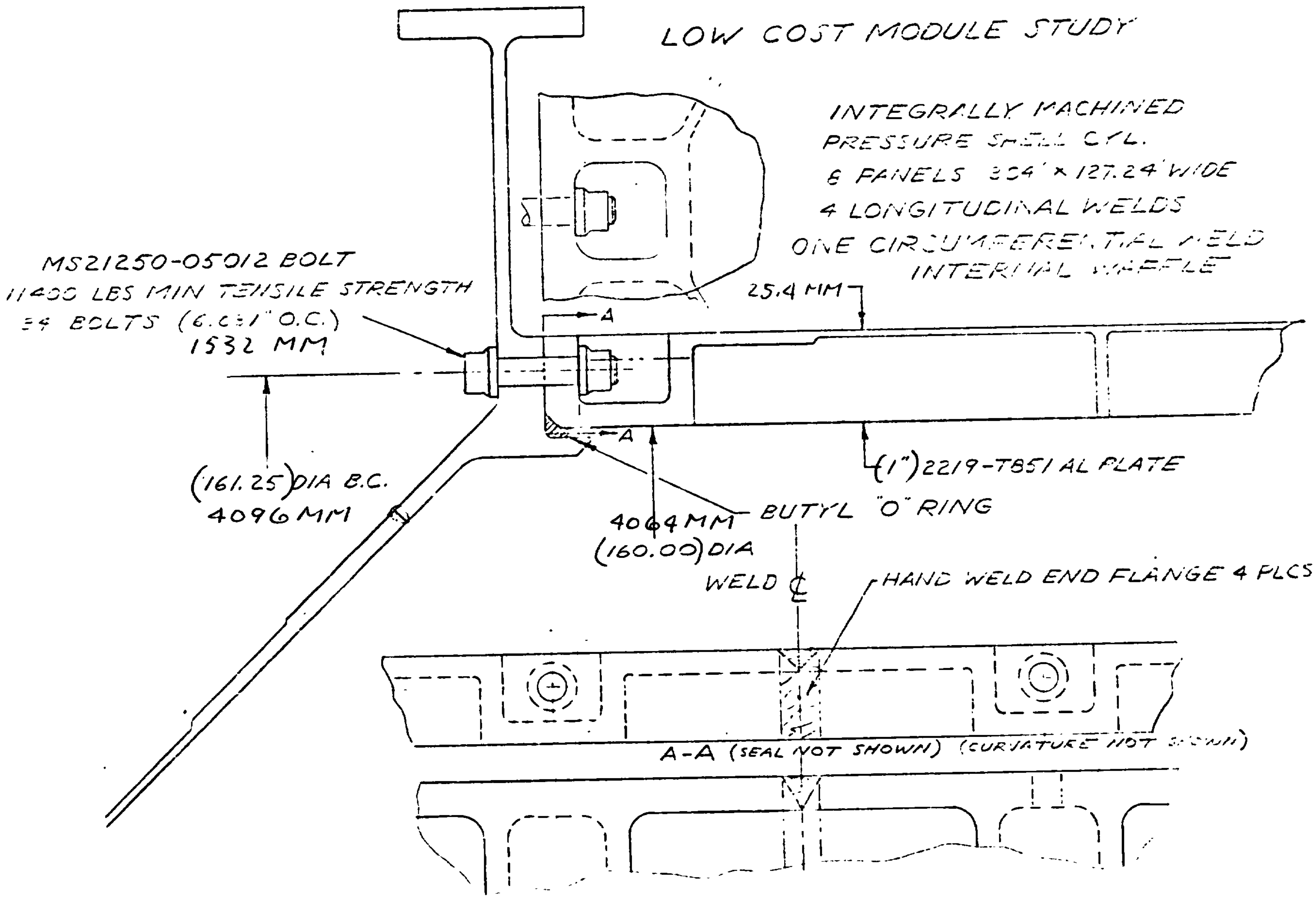

LOW COST MODULE STUDY
INTEGRALLY MACHINED
PRESSURE SHELL CYL.
6 PANELS 304' × 127.24' WIDE
4 LONGITUDINAL WELDS
ONE CIRCUMFERENTIAL WELD
INTERNAL WAFFLE
25.4 MM
MS21250-05012 BOLT
11400 LBS MIN TENSILE STRENGTH
34 BOLTS (6.031" O.C.)
1532 MM
A
(161.25) DIA B.C.
4096 MM
(1") 2219-T851 AL PLATE
4064 MM
(160.00) DIA
BUTYL "O" RING
WELD ℄
HAND WELD END FLANGE 4 PLCS
A-A (SEAL NOT SHOWN) (CURVATURE NOT SHOWN)

FIG 10

LOW COST MODULE TASK
ISOGRID CYLINDER AND EQUIPMENT SUPPORT PROVISIONS

26953

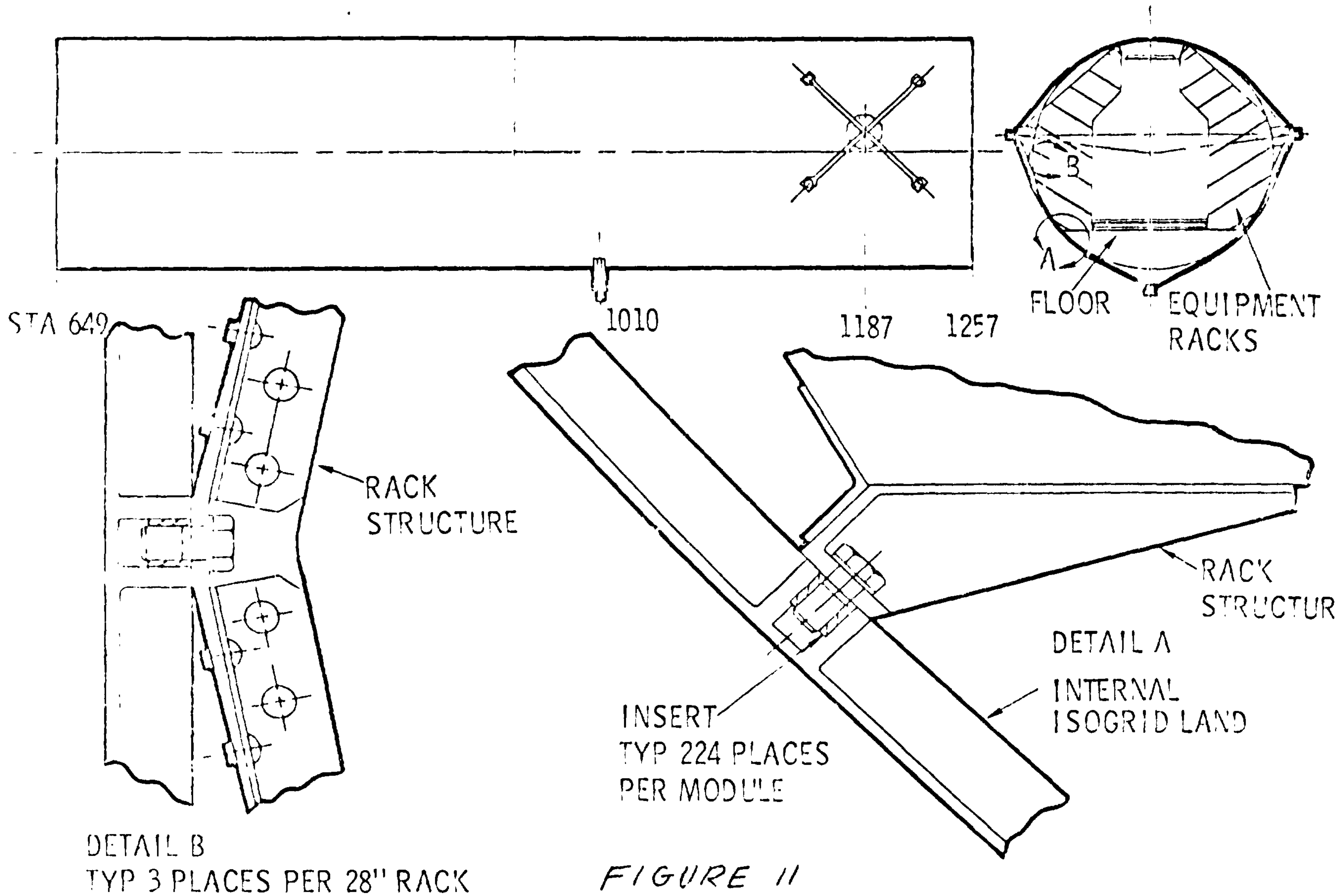

FIGURE 11

can be installed individually. The preferred approach will depend on the contents of a particular module, but with either approach, the isogrid shell minimizes requirements for secondary structure, but requires that socket wrench clearance through the racks be maintained to permit installation of the mounting bolts.

STRUCTURAL COSTS

The costs of engineering, manufacturing, and materials for the cylinder configurations shown in Figures 7 and 8, are summarized in Table 2. In addition to design layouts, analysis, and production drawings, the engineering estimate includes the system costs for sustaining engineering and liaison.

The materials and manufacturing costs for the monocoque cylinder are changed from those given at the January 28 presentation to reflect the substitution of stretch-formed extrusions for machined ring forgings for the three frames required to distribute the launch loads with the monocoque skins. With a materials cost of $66,000 for the three large ring forgings, they are not a competitive alternative for stretch-formed extrusions with a materials cost of $2,800.

SUMMARY

As indicated by the results summarized in Table 2, structural costs cannot be used as the criteria for choosing between the isogrid and monocoque cylinder configurations. The difference in cost is within the accuracy of the engineering estimates alone. Alternative criteria must be reviewed to determine the superior approach.

The isogrid design provides a weight saving of about 1,500 lb and eliminates huckbolt penetrations of the pressure shell. The monocoque skins provide improved radiation and meteoroid shielding. Both configurations are compatible with installation of the complete complement of equipment as an integrated unit, or in individual racks, the preferred choice depending on the equipment inventory for a particular module.

From MDAC manufacturing experience on Saturn and Delta, coupled with the design and analysis capability shown in the external tank proposal, the isogrid

STRUCTURAL COSTS

LOW COST MODULE CYLINDER

BOLT-ON BULKHEAD OPTION

	ISOGRID	MONOCOQUE
ENGINEERING	$250,250	$311,500
LAYOUTS		
ANALYSIS	PARTS 8	PARTS 16
PRODUCTION DRQWINGS	COUNT	COUNT
SUST. ENGINEER (LIASON & CHGS)	(8 production drawings & 4 layouts)	(16 production drawings & 6 layouts)
PRODUCTION (AVERAGE UNIT COST BASED ON RUN OF 6)		
MANUFACTURING	$177,101	$125,155
MATERIALS	73,690	63,773
	$50.k041 * 501,041	$500,428 *

*Does not include end bulkheads or secondary structure

TABLE 2

cylinder is preferred. Another company, without this background experience, would, in all probability, prefer the monocoque configuration. Both appear to present equally viable low-cost approaches for the Space Station module.

Part 6

MASS PROPERTIES

MASS PROPERTIES

This material presents the preliminary mass properties that have been generated for the SCB and related objective element hardware. The first section contains the individual elements, with the second section being the summary of the various elements in the SCB program options configurations as illustrated in the referenced figures. The third section contains OTV mass properties.

SCB MODULES AND OBJECTIVES MASS PROPERTIES OF ELEMENTS

Preliminary mass properties have been generated for most elements based on definitions developed to date. In all cases a 25% contingency on total mass was added for lack of detailed design definitions. The actual design requirements and definitions are contained in the Volume 2 of this report.

Figures 1 through 6 present the mass statements, CG's, and MOI's plus graphic epresentations for the coordinate axes references.

The next five figures illustrate and summarize the total mass of all major elements used in the various SCB configurations.

Figure 7 contains the space construction material handling equipment; Figure 8 the space construction tooling jigs/fixtures. Detailed mass properties for the universal truss assembly jig and solar collector F/A jig can be found in Figures 6 and 5 respectively. Figure 9 lists the space construction tooling/equipments mass. Figure 10 lists the space construction support modules mass summaries and module sizes. Figure 11 is the listing of the SCB modules.

SCB CONFIGURATION COMPUTERIZED MASS PROPERTIES

An analysis of typical configuration buildup was made using the previously defined elements plus the SCB modules as defined in the Volume 2 of this

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report. The computer program used is the MDAC H253, which prints H for the longitudinal cg (Xo), V for the vertical (Zo) and L for the lateral (Yo). All inputs were in English units but are converted by the H253 program to international units at the summary level. The specific characteristics of the resulting cg's, moments of inertia, products of inertia and direction cosine are highly dependent upon configurations and buildup schemes. Therefore, mass properties were generated for three different buildup options.

The first, the SCB (L') is a Shuttle tended-strongback configuration as illustrated in Figure 12. Five steps that were generated are described in Table 1.

The second configuration is another L' option, but with direct growth for a permanently manned SCB. Figure 13 illustrates this configuration and Table 7 is the summary of configuration steps.

The final configuration is the direct growth, permanently manned, 7-man SCB with full fabrication and assembly capability. Figure 14 illustrates this configuration. The mass properties model used a 30m radiometer, the MBL antenna, and TA-2, which is illustrated. Table 16 lists the steps. To define the optimum location and related impact for RCS, CMG's, etc, the Orbiter was clocked from the +Z to the -Z and then +Y in Tables 27, 28, and 29.

OTV MASS PROPERTIES

The OTV mass was defined using DAKTUG, an MDAC-developed interaction computer program. Using an external data file and program prompting questions for subsystem and design options for DAKTUG to define the interrelation between subsystems and then sizing the OTV, the resulting printout options give areas, volumes, configuration dimensions, detailed burnout mass, detailed propellant printouts, performance capability, power level, etc. Table 38 is an example of this printout and is for the OTV-1 booster stage.

The advantage of this program, beyond that of rapid access to detailed mass estimates and sizing conditions, is that subsystems have been integrated with other subsystems for related mass and sizing impacts as applicable. As an example, a change in usable propellant would impact the tank size and related structure, plus PU system, wiring runs, paint, layers of insulation, vented propellant, etc. Another example would be if mission duration was changed; power, RCS, vented propellant, again tankage and resulting resizing if the resize option was selected. If not, then shortages or excess tankage capacity is printed out.

Details of the subsystems were defined and integrated during the Phase-B Cryogenic Tug Study. Therefore only a 10% contingency was chosen based on the depth associated with that study and the similarity between these vehicles.

Table 39 is the configuration printout that references the dimensions based on the data files and program options. All units are in inches with a summary of total propellant loaded and the tankage capacity. Tankage volume is also included. Current Tank Diameter is 161.4 inches and the program will be rerun to correct for this.

Table 40 is an option table giving the detailed printout for surface areas and envelope volumes. Table 41 is the detailed burnout weight (lbM), including primary and secondary structures. The majority of secondary structure is identified as supports under the subheading Body Structure. This includes support allowance for wiring, avionics mounting, RCS, and fuel cell mounts, etc. The majority of these are based on past programs using a variety of functional relationship for curve fitting. The thrust structures and sumps are similar examples. The thermal control and propulsion subsystems were handled in a similar manner, with the avionics being a series of subroutine data files for the option selection. Instrumentation and circuitry is also dependent upon stage size. The electrical power was sized for a 0.7 kW average power level for the OTV plus an allowance of 0.3 kW average for payload support. The power water storage with fuel cells is 25%, with

dumping during main engine burns. The avionics thermal control assumes $15m^2$ ($50 \ ft^2$) of heat sink surface area with local housing support for the avionics mounted there.

The residuals include FPR, PU, pressurization gases, and system trapped gases › ' propellants.

Table 42 includes the inflight losses plus the resulting propellant bulk density and mixture ratio. Initial sizing MR was 6:1 with the CAT IIA RL-10 with trapped gases, reserves, and losses shifting the ratio by 3 to 4 %.

Table 43 is a comparison summary of the OTV-1 and -2 stages. The resulting λ' using all expendables to define stage efficiency λ' is 0.9205 and 0.9290. Figure 15 is a summary of the mass for the fueled OTV-1.

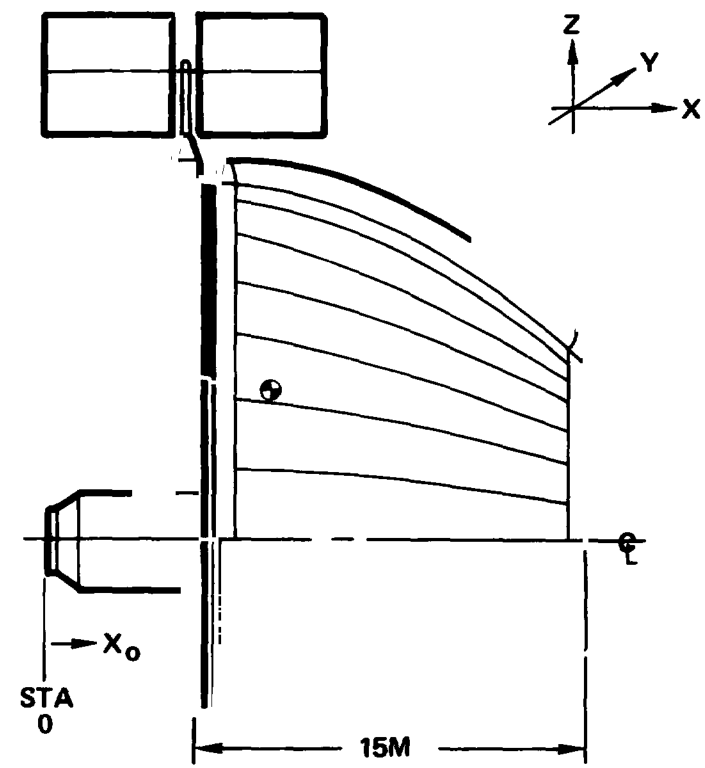
FIGURE 1

30M RADIOMETER

MASS PROPERTIES

27711

ITEM	MASS - Kg
ANTENNA SHELL	4,653
STRUCTURE	3,523
WHEEL & COUNTERBALANCE	1,878
SOLAR PANELS	210
CONTROL MODULE	2,074
SUBTOTAL	12,338
CONTINGENCY	3,085
TOTAL	15,423



MASS - Kg

15,423 Kg (34,000 LB)

CENTER OF GRAVITY

X	Y	Z
9.4	6.1	0

(M)

MOMENT OF INERTIA

ROLL	YAW	PITCH
1.60	1.03	1.68

(Kg · M^2 X 10^6)

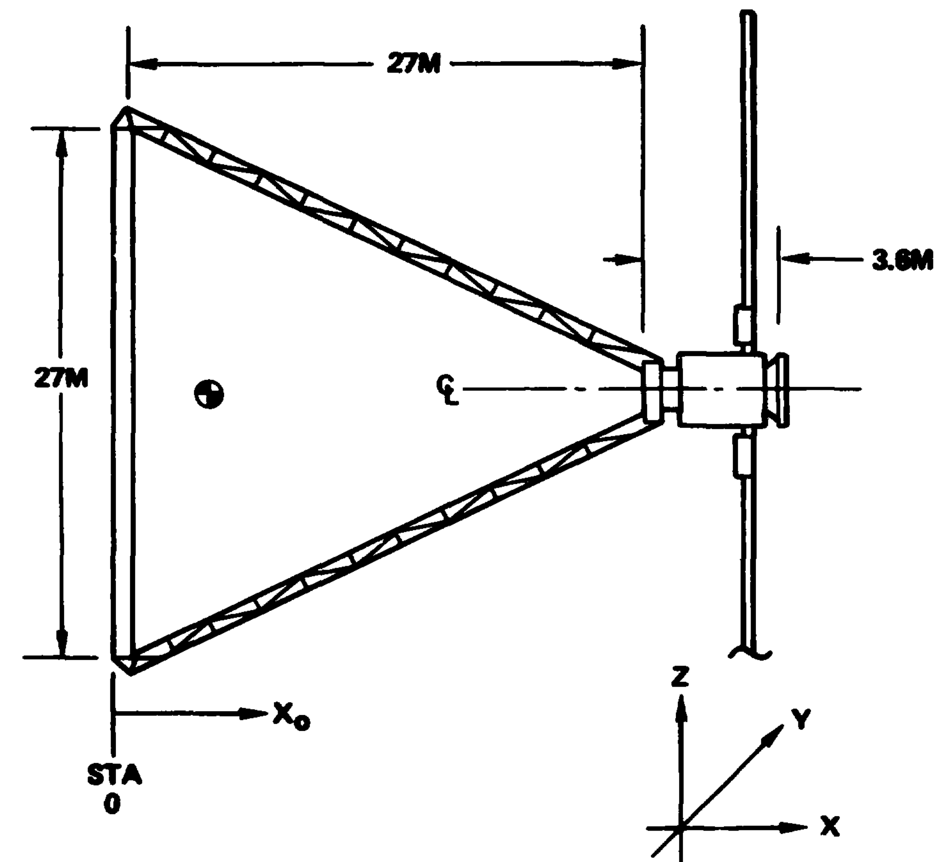
CR6-3-2
27710

FIGURE 2

MULTIPLE BEAM LENS ANTENNA

MASS PROPERTIES

ITEM	MASS - Kg
LENS	20,743
TRUSS BEAMS	668
FEEDER ARRAY	185
SOLAR PANELS	508
CONTROL MODULE	1,162
SUBTOTAL	23,266
CONTINGENCY	5,817
TOTAL	29,083



MASS

29,083 (65,700 LB)

CENTER OF GRAVITY

X	Y	Z
2.9	0	0

(M)

MOMENT OF INERTIA

ROLL	YAW	PITCH
2.60	3.14	3.25

$(Kg - M^2 \times 10^6)$

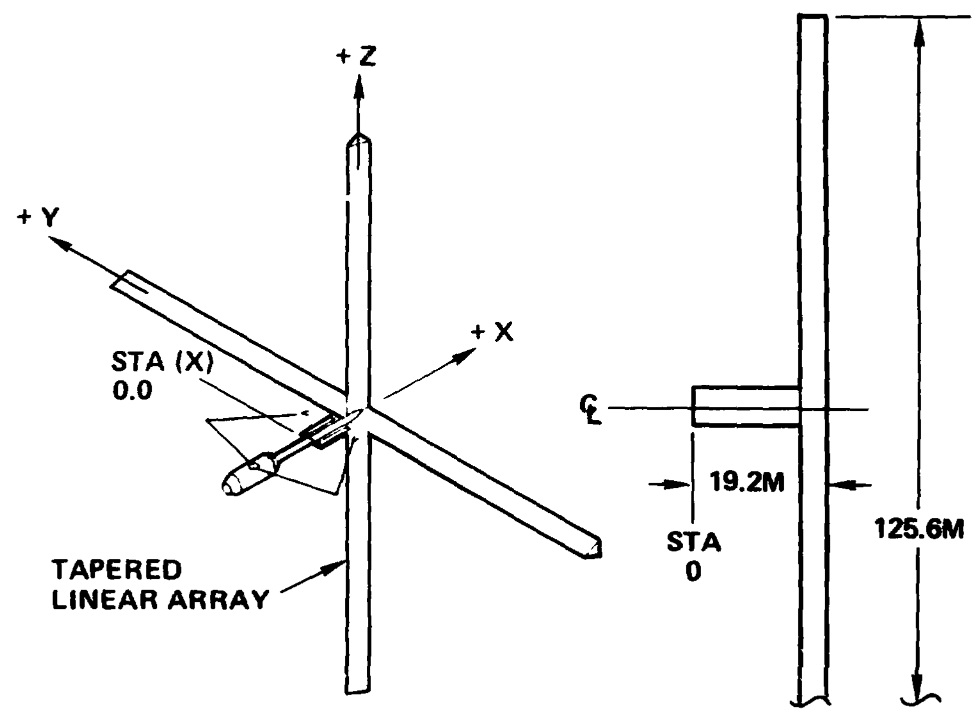
CR5-3-2
27712

FIGURE 3

SPS TEST ARTICLE - 1 (TA-1)

MASS PROPERTIES

ITEM	MASS - Kg
SOLAR ARRAY	1,520
MICROWAVE ANTENNA	2,288
ROTARY JOINT & STANDOFF	502
SUPPORT SUBSYSTEMS	431
SUBTOTAL	4,741
CONTINGENCY	1,185
TOTAL	5,926



MASS

5,926 Kg (13,064 LB)

CENTER OF GRAVITY

X	Y	Z
13,72	0.0	0.0

(M)

MOMENT OF INERTIA

ROLL	YAW	PITCH
2.953	1.615	1.707

($Kg \cdot M^2 \times 10^6$)

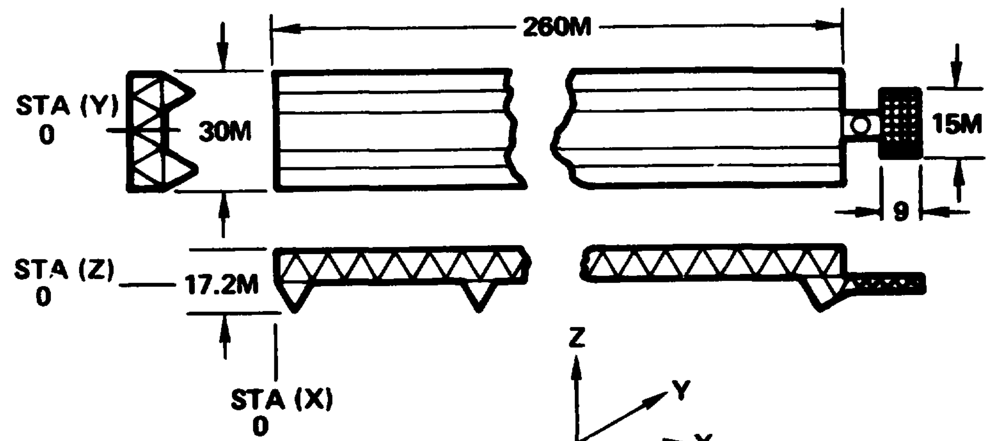
27709

FIGURE 4

SPS TEST ARTICLE - 2 (TA-2)

MASS PROPERTIES

ITEM	MASS - Kg	
SOLAR COLLECTOR	14,316	
STRUCTURE		12,027
SOLAR CELL BLANKETS		1,790
REFECTORS		499
MICRO WAVE ANTENNA	2,098	
ROTARY JOINT & SUPPORT	1,150	
SUPPORT SUBSYSTEMS	300	
SUBTOTAL	17,864	
CONTINGENCY	4,466	
TOTAL	22,330	



MASS

22,330 Kg (49,227 LB)

CENTER OF GRAVITY

X	Z	Y
150.5	1.0	0.0

(M)

MOMENT OF INERTIA

ROLL	YAW	PITCH
1.54	143.1	141.9

($Kg - M^2 \times 10^6$)

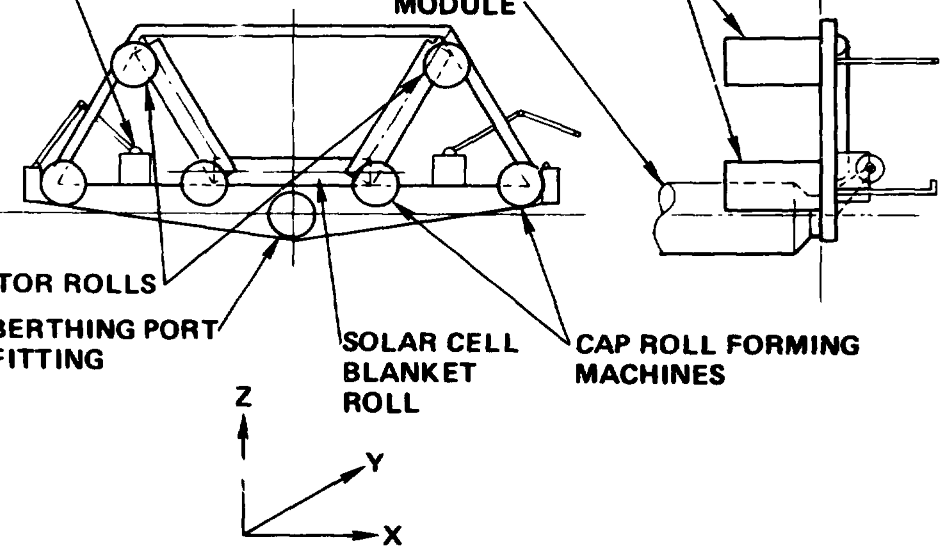
CR5-3-2
27707

FIGURE 5

TA-2 AUTOMATED SOLAR COLLECTOR

FAB AND ASSEMBLY JIG MASS PROPERTIES

ITEM	MASS-Kg
BEAM MACHINES (6)	5,442
DOCKING PROVISIONS/TUNNEL	771
CO AND FAB SUPT PROV	550
AUTOMATIC ROBOTS (2)	1,360
FABRICATION FIXTURES	1,957
FRAMES	1,357
FITTINGS	600
STOWAGE AND MATERIAL SUPT	500
SUBTOTAL	10,530
CONTINGENCY	2,630
TOTAL	13,160



MASS
13,160 Kg (29,018 LB)

CENTER OF GRAVITY

X	Z	Y
-0.76	2.42	0.00

(M)

MOMENT OF INERTIA

ROLL	YAW	PITCH
0.852	0.870	0.138

($Kg\text{-}M^2 \times 10^6$)

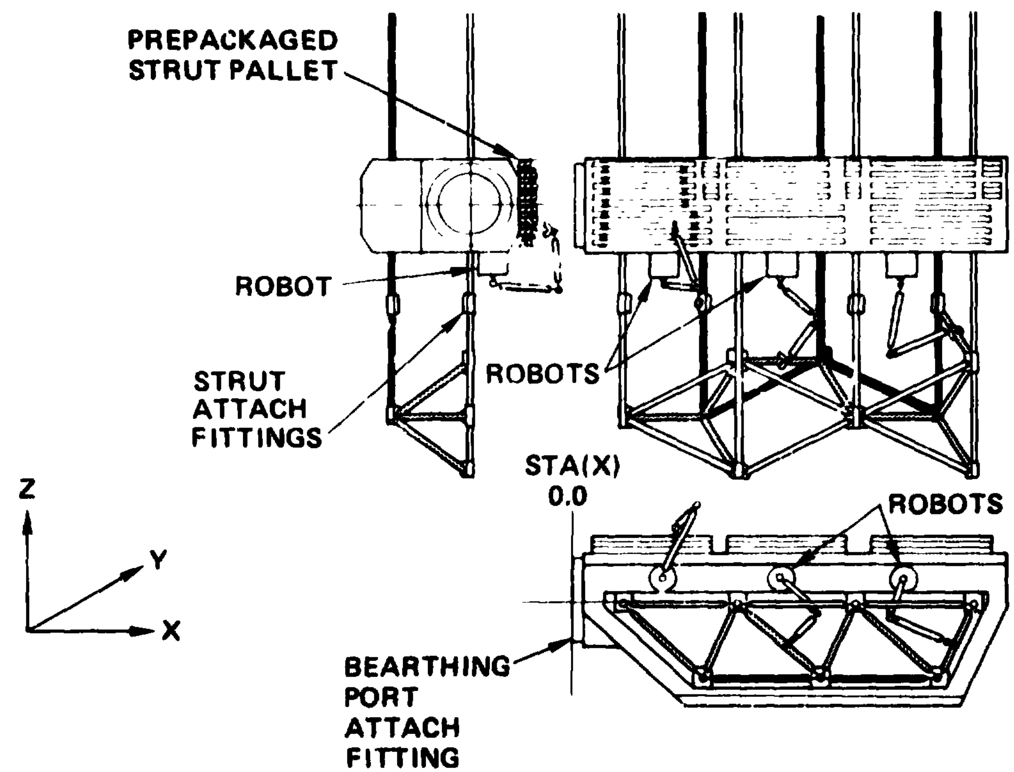
FIGURE 6

CR5-3-2
27708

UNIVERSAL TRUSS ASSEMBLY JIG, TA-2 ANTENNA

MASS PROPERTIES

ITEM	MASS-Kg
FABRICATION FIXTURE	1,837
ROBOTS (3)	2,040
ATTACHMENT MECHANISMS (7)	350
CC AND FAB SUPT PROV	250
STOWAGE AND MATERIAL SUPT	224
SUBTOTAL	4,701
CONTINGENCY	1,179
TOTAL	5,880



MASS	CENTER OF GRAVITY			MOMENT OF INERTIA		
	X	Z	Y	ROLL	YAW	PITCH
5,880 Kg (12,954 LB)	TBD	TBD	TBD	TBD	TBD	TBD
		(M)			($Kg \cdot M^2 \times 10^6$)	

FIGURE 7

CR5-3-2
27344

SPACE CONSTRUCTION MATERIAL HANDLING EQUIPMENT

MASS SUMMARY

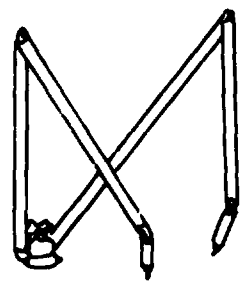
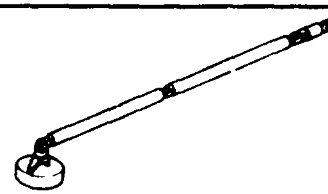
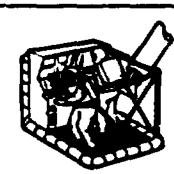
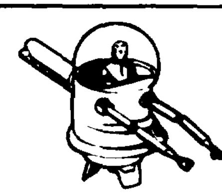
		CHARACTERISTICS			
		PRODUCTS	UNIT SIZE-m	UNIT MASS-KG	NO. OF STS LAUNCHES
MOBILE CRANE		● SCB ASSEMBLY ● 30m RADIOMETER ● 100m RADIOMETER ● 300m RADIOMETER ● MBL ● TA-1 ● TA-2	35m LGX 0.6m DIA ARMS	1590	1
SCB RMS		● TA-1 ● 30m RADIOMETER	15m LG x .38m DIA ARMS	1060	~ 1/10
CHERRY PICKER PLATFORM		● ALL MISSION ELEMENTS	2m x 3m + 1m	1875	1/5
CHERRY PICKER PLATFORM W/MANIPULATORS		● ALL MISSION ELEMENT	1m DIA x 2.13m	2500	1/5

FIGURE 8

CR5-3-2
27345

SPACE CONSTRUCTION TOOLING JIGS/FIXTURES

MASS SUMMARY

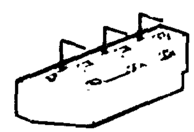
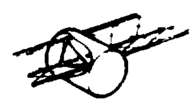
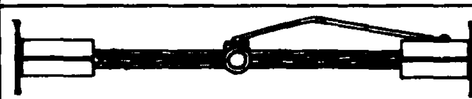
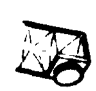
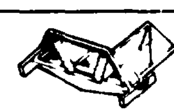
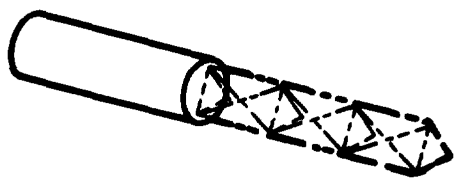
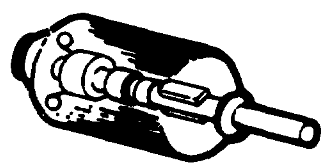
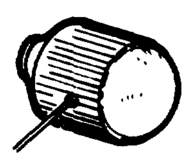
ASSEMBLY JIGS/FIXTURES TRUSSES, PLATFORMS, TOOLING BEAMS		PRODUCTS	CHARACTERISTICS: UNIT SIZE-M	UNIT MASS-KG	NO. OF STS LAUNCHES
UNIVERSAL TRUSS ASSEMBLY JIG		• TA-2 ANTENNA • TA-1 ANTENNA • UNIVERSAL STRONGBACK FIXTURE	13.5 x 4 x 2.5	5880	7/8
4M TRUSS ASSEMBLY JIG		• TA-1 ANTENNA • STRONGBACK FIXTURE	4.4 DIA x 5.6	1480	1/3
ASSEMBLY BEAM		• 30m RADIO • MBL • TA-1	3 x 2 x 20	+ 700	1
STRONGBACK		• 100m RADIO • TA-1 • 300m RADIO • 30m RADIO	3 x 2 x 40	+1400	1
INDEXING TURNTABLE		• 30m RADIOMETER • 100m RADIOMETER • 300m RADIOMETER • MBL	2.2 DIA x 0.6	230	1/20
SOLAR COLLECTOR F/A JIG		• TA-2 SOLAR COLLECTOR	110 x 40 x 7	7720	1

FIGURE 9

SPACE CONSTRUCTION TOOLING/EQUIPMENT

MASS SUMMARY

FABRICATION UNITS TUBING, CAPS, FITTING, ETC		PRODUCTS	UNIT SIZE - M	UNIT MASS-KG	NO. OF STS LAUNCHES
METAL ROLL FORMING UNIT		• TA-2 SOLAR COLLECTOR CAP BEAMS	2 DIA x 6.6	907	1/6
COMPOSITES FABRICATION UNIT		• TA-1 ANTENNA • TA-2 ANTENNA • STRONGBACK FIXTURF	4.4 DIA x 6	4660	1/2
COMPOSITES 20CM TUBE FAB UNIT		• TA-1 ANTENNA • STRONGBACK FIXTURE	4.4 DIA x 3.5	2350	1/4

CR5-3-2
27343

FIGURE 10

SPACE CONSTRUCTION SUPPORT MODULES

MASS SUMMARY

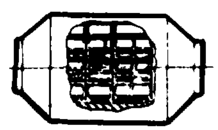
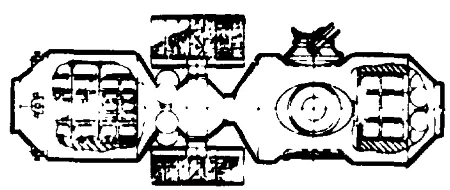
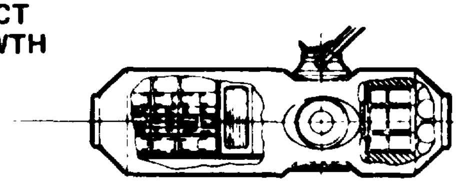
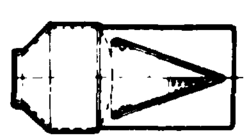
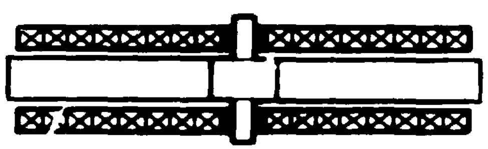
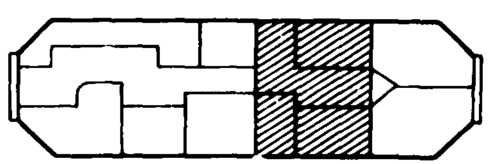
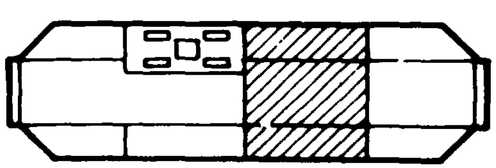
SUPPORT MODULES	FEATURES	CHARACTERISTICS MODULE SIZE-M	MODULE MASS-KG
STRONGBACK 	• PRESSURIZED • 2 MAN EVA AIRLOCK • CONTROL & MONITOR • TEST, CALIBRATION & C/O EQUIP	4.4 DIA x 7.5	5440
SINGLE SHUTTLE LAUNCH 	• SOLAR ARRAY • RCS • PRESSURIZABLES • EVA AIRLOCK • MIN CONTROL • CRANE	4.4 DIA x 18.28	14730
DIRECT GROWTH 	• PRESSURIZED • FULL CONTROL • TOTAL EVA SUPPORT • CRANE	4.4 DIA x 15.24	14520
TRUSS F/A MODULE 	• FABS 20CM TUBES • MAKES 4MX 3M BEAMS • PRESSURE SECTION • AUTOMATIC TUBE • SEMI-AUTO BEAM ASSEMBLY	4.4 DIA X 9.1	3830

FIGURE 11

SCB STANDARD MODULE MASS SUMMARY

CR5-3-2

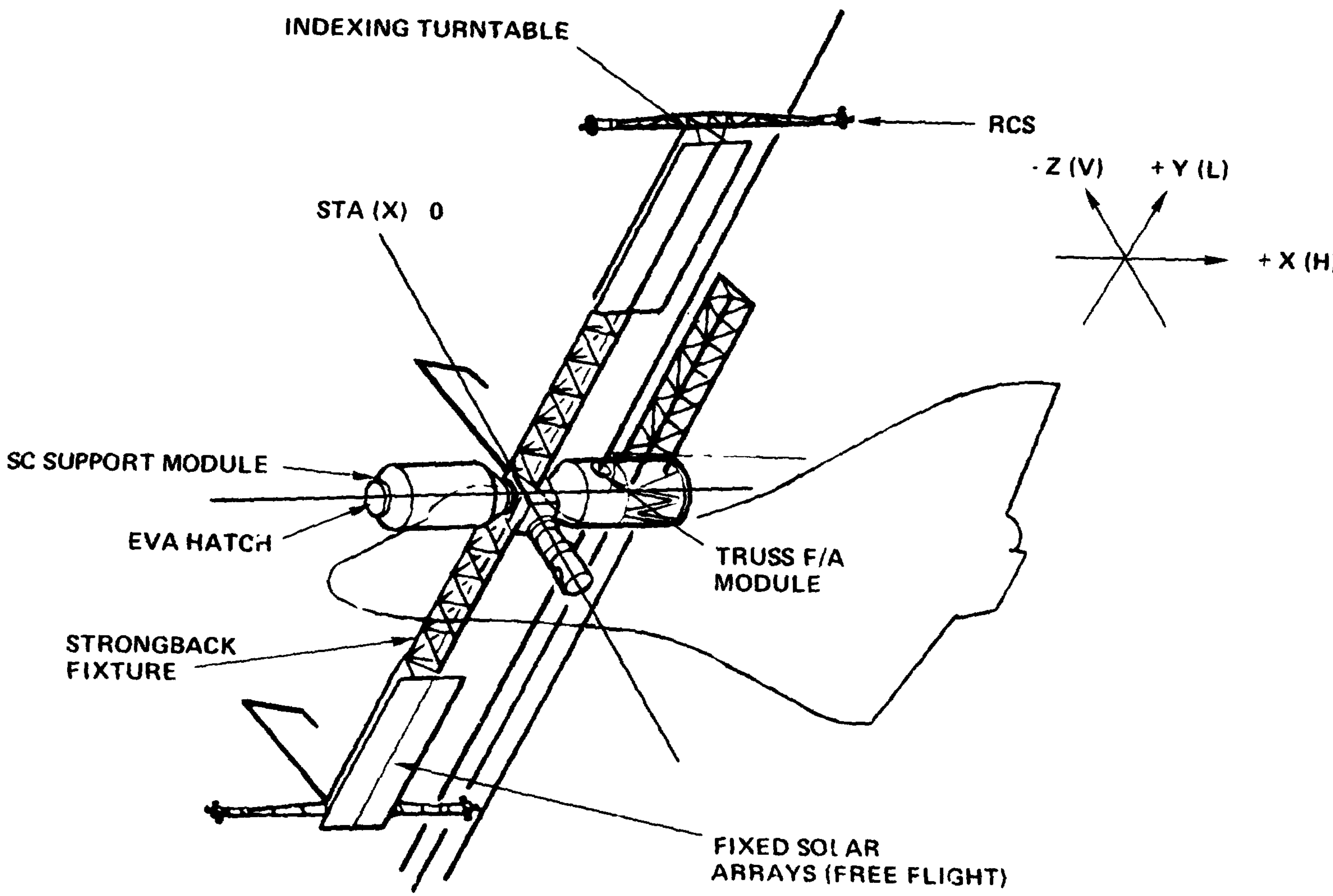
SCB MODULES	FEATURES	MODULE SIZE-M	MODULE MASS-KG
CORE 	GUIDANCE & CONTROL, RCS, FUEL CELLS, INFORMATION, ETC.	4.41 DIA * 15.2	15,300
POWER 	ARRAYS, GAS STOWAGE, REPRESSURIZATION GASES, ETC.	4.41 DIA * 15.2	12,800
CONTROL/HABITATION 	CREW QUARTERS, HYGIENE, ECLS, CONTROL, ETC.	4.41 DIA * 15.2	13,300
CREW SUPPORT 	GALLEY, RECREATION, ECLS, MEDICAL, ETC.	4.41 DIA * 15.2	13,200

CR5-3-2
27014

FIGURE 12

SCB(L') SHUTTLE-TENDED--STRONG BACK MASS PROPERTIES COORDINATE AXES

4-7-MAN FABRICATION AND ASSEMBLY

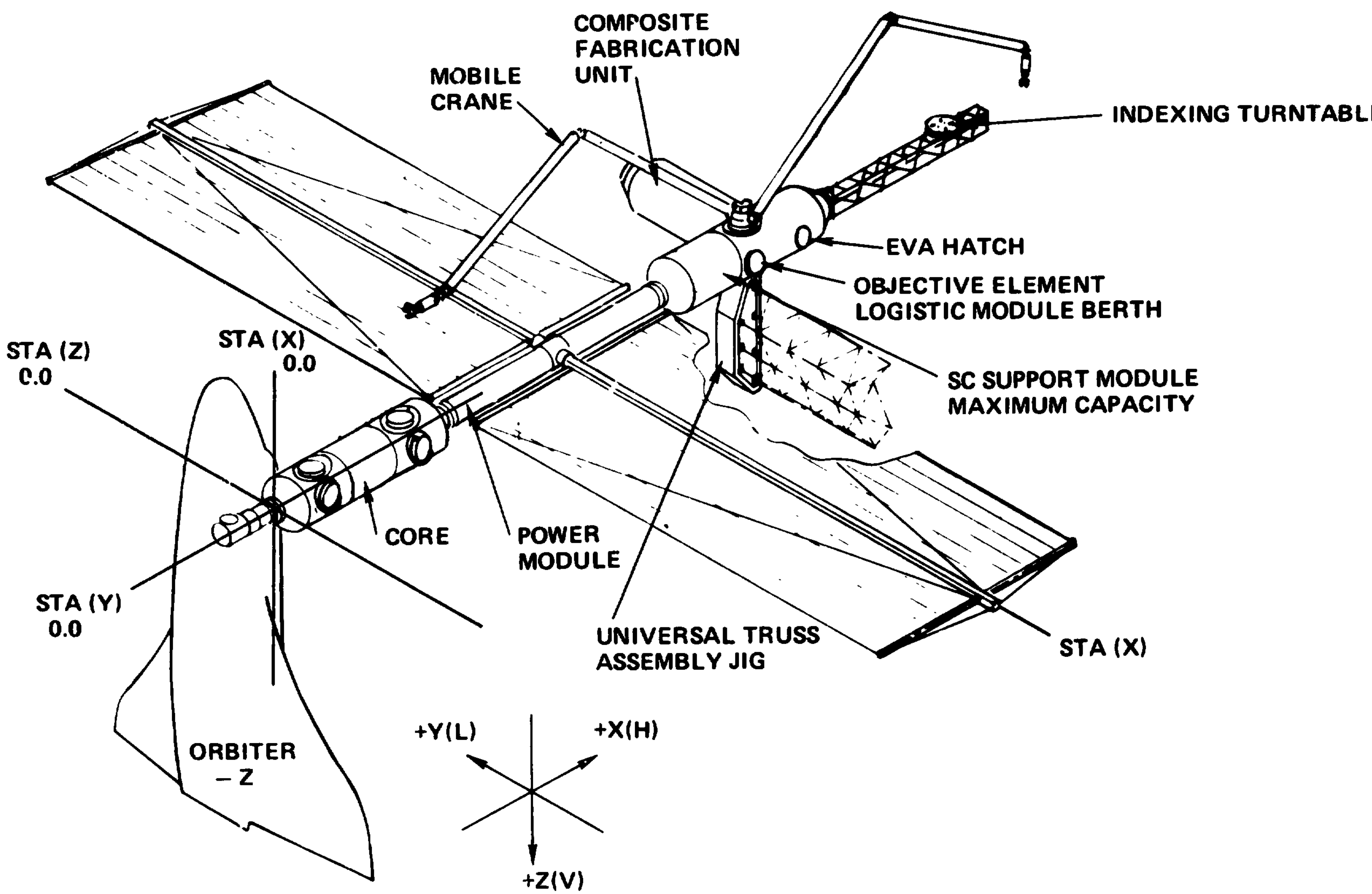


CR5-3-2
27120

FIGURE 13

SCB(L') SHUTTLE-TENDED--DIRECT GROWTH MASS PROPERTIES COORDINATE AXES

7-MAN FABRICATION AND ASSEMBLY

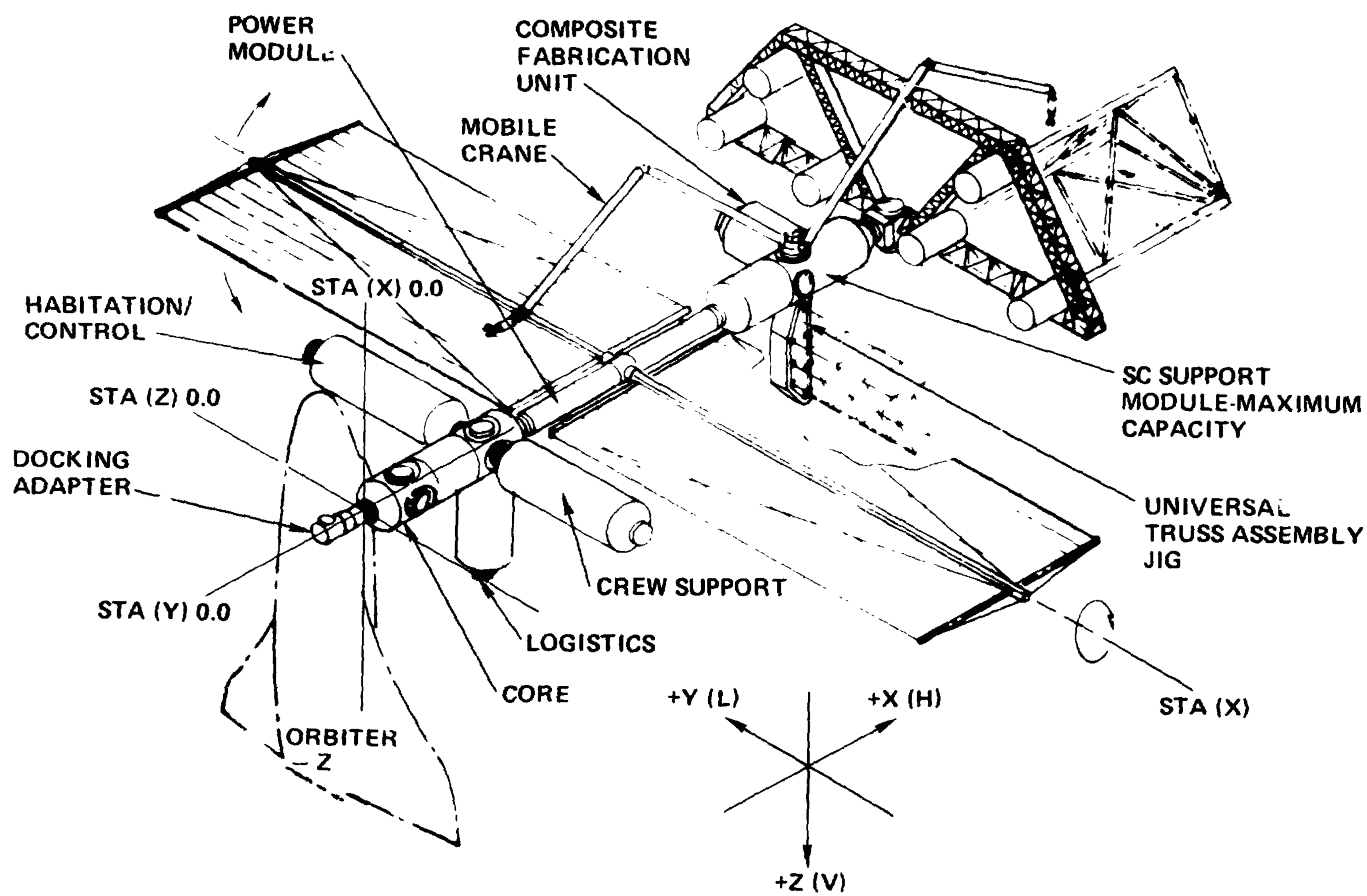


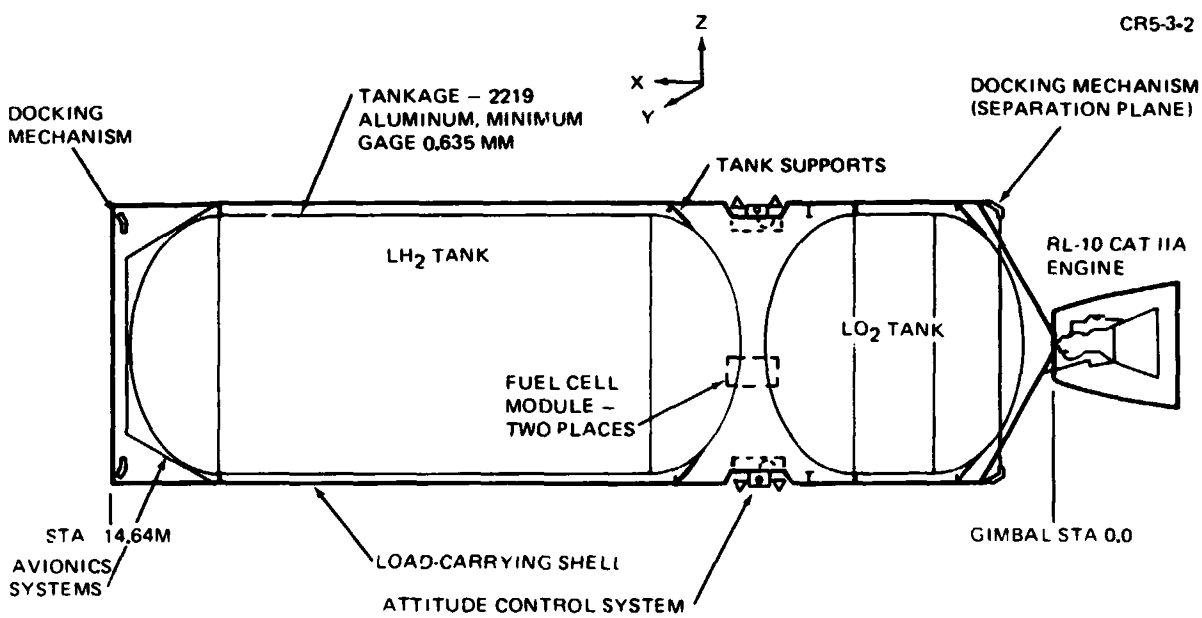
CR5-3-2
27121

FIGURE 14

SCB(L) PERMANENTLY MANNED--DIRECT GROWTH MASS PROPERTIES COORDINATE AXES

7-MAN FABRICATION AND ASSEMBLY





	CENTER OF GRAVITY			MOMENT OF INERTIA		
MASS	X	Y	Z	ROLL	YAW	PITCH
63,424 KG (139,822 LBM)	6 6M	0.0	0 0	10 6	147 0	147 4

Figure 15. Fueled OTV Mass Properties

$KG \cdot M^2 \cdot 10^3$

Table 1

SCB (L') SHUTTLE TENDED-STRONGBACK
MASS PROPERTIES STEPS

Table Number	Configuration Number	Description
2	501	Strongback with support systems
3	502	501 plus SC support module
4	503	502 plus Orbiter (+Z)
5	504	503 plus 30m radiometer (-Y)
6	505	503 less Orbiter

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION TABLE 2

ITEM DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
501 STRONG BACK	3086.00	0.00	-34.00	0.00	.2604900E+09	.2613500E+09	.1694000E+07
502 ARRAYS	2279.00	0.00	40.00	0.00	0.	0.	0.
503 HUB MODULE	388.00	0.00	0.00	0.00	.1000000E+08	.9300000E+07	.1040000E+08
CONF. 501 TOTAL	5753.00	0.00	-2.39	0.00	.2776709E+09	.2706500E+09	.1927489E+08
					SL-FT2	SL-FT2	SL-FT2
					.5993250E+05	.5841712E+05	.4160293E+04
	KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
	2609.07	0.00	-.06	0.00	.8125779E+05	.7920320E+05	.5640616E+04

E CONST BASE OPTION L. DA KASULKA 19JAN77 PAGE A 2

TABLE 3 (1/2)

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
501	STRONG BACK	3086.00	0.00	-34.00	0.00	.2604900E+09	.2613500E+09	.1694000E+07
502	ARRAYS	2279.00	0.00	40.00	0.00	0.	0.	0.
503	HUB MODULE	388.00	0.00	0.00	0.00	.1000000E+08	.9300000E+07	.1040000E+08
505	CONTROL MOD	12000.00	-375.00	0.00	0.00	.3120000E+08	.2801000E+08	.3115000E+08
506	RMS+TURRET	2336.00	0.00	-127.00	0.00	0.	0.	0.
CONF. 502	TOTAL	20089.00	-224.00	-15.45	0.00	.3417840E+09	.9781457E+09	.7628236E+09
						SL-FT2	SL-FT2	SL-FT2
						.7377068E+05	.2111230E+06	.1646479E+06
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		9110.66	-5.69	-.39	0.00	.1000199E+06	.2862452E+06	.2232332E+06

E CONST BASE OPTION L. DA KASULKA 19JAN77 PAGE A 3

F253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION — TABLE 3 (2/2)

PRINCIPAL AXES DATA

CONFIGURATION 502

WEIGHT	20089.00	LBMASS			9110.66	KGMS
H-ARM	-224.00	INCHES			-5.69	METERS
V-ARM	-15.45	INCHES			-.39	METERS
L-ARM	0.00	INCHES			0.00	METERS
ROLL MOI	.3417840E+09	LB/IN2	.7377068E+05	SL-FT2	.1000199E+06	KG-M2
YAW MOI	.9781457E+09	LB/IN2	.2111230E+06	SL-FT2	.2862452E+06	KG-M2
PITCH MOI	.7628236E+09	LB/IN2	.1646479E+06	SL-FT2	.2232332E+06	KG-M2
ROLL POI	0.	LB/IN2	0.	SL-FT2	0.	KG-M2
YAW POI	0.	LB/IN2	0.	SL-FT2	0.	KG-M2
PITCH POI	-.6953865E+08	LB/IN2	-.1500923E+05	SL-FT2	-.2034984E+05	KG-M2

PRINCIPAL MOI 1	.9856559E+09 LB/IN2	.2127440E+06 SL-FT2	.2884430E+06 KG-M2
DIRECTION COSINES	COSH= .1073763E+00	COSV= .9942184E+00	COSL= .2613284E-59
PRINCIPAL ANGLES	FROM +H= 83.84 DEG	FROM +V= 6.16 DEG	FROM +L= 90.00 DEG
PRINCIPAL MOI 2	.3342736E+09 LB/IN2	.7214967E+05 SL-FT2	.9782210E+05 KG-M2
DIRECTION COSINES	COSH= .9942184E+00	COSV= -.1073763E+00	COSL= -.1292924E-60
PRINCIPAL ANGLES	FROM +H= 6.16 DEG	FROM +V= 96.16 DEG	FROM +L= 90.00 DEG
PRINCIPAL MOI 3	.7628236E+09 LB/IN2	.1646479E+06 SL-FT2	.2232332E+06 KG-M2
DIRECTION COSINES	COSH= .2307514E-59	COSV= .1282568E-58	COSL= .1000000E+01
PRINCIPAL ANGLES	FROM +H= 90.00 DEG	FROM +V= 90.00 DEG	FROM +L= 0.00 DEG

DESATURATION COEF. = .4846390E+01 (IPMAX+IPMID)/2 = .8742398E+09 LB/IN2, .1886960E+06 SL-FT2

E CONST BASE OPTION L+ . DA KASULKA 19JAN77 PAGE C 1

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION TABLE 4 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
501	STRONG BACK	3086.00	0.00	-34.00	0.00	.2604900E+09	.2613500E+09	.1694000E+07
502	ARRAYS	2279.00	0.00	40.00	0.00	0.	0.	0.
503	HUB MODULE	388.00	0.00	0.00	0.00	.1000000E+06	.9300000E+07	.1040000E+08
505	CONTROL MOD	12000.00	-375.00	0.00	0.00	.3120000E+08	.2801000E+08	.3115000E+08
506	RMS+TURRET	2336.00	0.00	-127.00	0.00	0.	0.	0.
507	ORBITER	200000.00	619.00	233.00	-.40	.3922700E+10	.3007900E+11	.2881800E+11
CONF. 503	TOTAL	220089.00	542.05	210.32	-.36	.5391369E+10	.4403039E+11	.4368094E+11
						SL-FT2	SL-FT2	SL-FT2
						.1163674E+07	.9503522E+07	.9428098E+07
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		99813.61	13.77	5.34	-.01	.1577734E+07	.1288508E+08	.1278282E+08

E CONST BASE OPTION L, DA KASULKA 19JAN77 PAGE A 4

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

PRINCIPAL AXES DATA

CONFIGURATION 503

TABLE 4 (2/2)

WEIGHT	220089.00 LBMASS		99813.61 KGMS
H-ARM	542.05 INCHES		13.77 METERS
V-ARM	210.32 INCHES		5.34 METERS
L-ARM	-.36 INCHES		-.01 METERS
ROLL MOI	.5391369E+10 LB/IN2	.1163674E+07 SL-FT2	.1577734E+07 KG-M2
YAW MOI	.4403039E+11 LB/IN2	.9503522E+07 SL-FT2	.1288508E+08 KG-M2
PITCH MOI	.4368094E+11 LB/IN2	.9428098E+07 SL-FT2	.1278282E+08 KG-M2
ROLL POI	-.1814258E+07 LB/IN2	-.3915853E+03 SL-FT2	-.5309198E+03 KG-M2
YAW POI	-.6155725E+07 LB/IN2	-.1328652E+04 SL-FT2	-.1801415E+04 KG-M2
PITCH POI	.3753983E+10 LB/IN2	.8102599E+06 SL-FT2	.1098568E+07 KG-M2

PRINCIPAL MOI 1	.4439173E+11 LB/IN2	.9581514E+07 SL-FT2	.1299083E+08 KG-M2
DIRECTION COSINES	COSH= -.9581184E-01	COSV= .9953960E+00	COSL= .1710923E-02
PRINCIPAL ANGLES	FROM +H= 95.50 DEG	FROM +V= 5.50 DEG	FROM +L= 89.90 DEG
PRINCIPAL MOI 2	.5030028E+10 LB/IN2	.1085682E+07 SL-FT2	.1471991E+07 KG-M2
DIRECTION COSINES	COSH= .9953994E+00	COSV= .9581225E-01	COSL= -.1630293E-03
PRINCIPAL ANGLES	FROM +H= 5.50 DEG	FROM +V= 84.50 DEG	FROM +L= 90.01 DEG
PRINCIPAL MOI 3	.4368094E+11 LB/IN2	.9428098E+07 SL-FT2	.1278282E+08 KG-M2
DIRECTION COSINES	COSH= .3262064E-03	COSV= -.1687432E-02	COSL= .9999985E+00
PRINCIPAL ANGLES	FROM +H= 89.98 DEG	FROM +V= 90.10 DEG	FROM +L= .10 DEG

DESATURATION COEF. = .1097555E+03 (IPMAX+IPMID)/2 = .4403634E+11 LB/IN2, .9504806E+07 SL-FT2

E CONST BASE OPTION L+ DA KASULKA 19JAN77 PAGE C 2

H255 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION TABLE 5 (1/2)

ITEM DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
501 STRONG BACK	3086.00	0.00	-34.00	0.00	.2604900E+09	.2613500E+09	.1694000E+07
502 ARRAYS	2279.00	0.00	40.00	0.00	0.	0.	0.
503 HUT MODULE	381.00	0.00	0.00	0.00	.1000000E+08	.9300000E+07	.1040000E+08
505 CONTROL MOD	12000.00	-375.00	0.00	0.00	.3120000E+08	.2801000E+08	.3115000E+08
506 RMS+TURRET	2330.00	0.00	-127.00	0.00	0.	0.	0.
507 ORBITER	200000.00	619.00	233.00	-.40	.3922700E+10	.3007900E+11	.2881800E+11
508 30M RADIO	38600.00	0.00	-454.00	964.00	.5727100E+10	.5471500E+10	.3503400E+10
CONF. 504 TOTAL	258689.00	461.17	111.20	143.53	.5615311E+11	.6969252E+11	.7137678E+11
					SL-FT2	SL-FT2	SL-FT2
					.1212009E+08	.1935924E+08	.1539518E+08
	KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
	117319.27	11.71	2.82	3.65	.1643268E+08	.2624768E+08	.2087312E+08

E CONST BASE OPTION L? DA KASULKA 19JAN77

TABLE 5(2/2)

H?53 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 504

WEIGHT	258689.00 LBMASS		117319.27 KGMS
H-ARM	461.17 INCHES		11.71 METERS
V-ARM	111.20 INCHES		2.82 METERS
L-ARM	143.53 INCHES		3.65 METERS
ROLL MOI	.5615311E+11 LB/IN2	.1212009E+08 SL-FT2	.1643268E+08 KG-M2
YAW MOI	.8969252E+11 LB/IN2	.1935924E+08 SL-FT2	.2624768E+08 KG-M2
PITCH MOI	.7132678E+11 LB/IN2	.1539518E+08 SL-FT2	.2087312E+08 KG-M2
ROLL POI	-.2104091E+11 LB/IN2	-.4541472E+07 SL-FT2	-.6157426E+07 KG-M2
YAW POI	-.1717300E+11 LB/IN2	-.3706622E+07 SL-FT2	-.5025519E+07 KG-M2
PITCH POI	.1557973E+11 LB/IN2	.3362729E+07 SL-FT2	.4559261E+07 KG-M2
PRINCIPAL MOI 1	.1038294E+12 LB/IN2	.2241056E+08 SL-FT2	.3038472E+08 KG-M2
DIRECTION COSINES	COSH= -.9923530E-01	COSV= .8584124E+00	COSL= .5032698E+00
PRINCIPAL ANGLES	FROM +H= 95.70 DEG	FROM +V= 30.86 DEG	FROM +L= 59.78 DEG
PRINCIPAL MOI 2	.3384298E+11 LB/IN2	.7304670E+07 SL-FT2	.9903831E+07 KG-M2
DIRECTION COSINES	COSH= .7187497E+00	COSV= .4116053E+00	COSL= -.5603391E+00
PRINCIPAL ANGLES	FROM +H= 44.05 DEG	FROM +V= 65.69 DEG	FROM +L=124.08 DEG
PRINCIPAL MOI 3	.7949999E+11 LB/IN2	.1715928E+08 SL-FT2	.2326493E+08 KG-M2
DIRECTION COSINES	COSH= .6881506E+00	COSV= -.3061196E+00	COSL= .6578294E+00
PRINCIPAL ANGLES	FROM +H= 46.52 DEG	FROM +V=107.83 DEG	FROM +L= 48.87 DEG

DESATURATION COEF. = .4753229E+01 (IPMAX+IPMID)/2 = .9166472E+11 LB/IN2. .1978492E+08 SL-FT2

E CONST BASE OPTION L+ DA KASULKA 19JAN77 PAGE C 3

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION TABLE 6 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
501	STRONG BACK	3080.00	0.00	-34.00	0.00	.2604900E+09	.2613500E+09	.1694000E+07
502	ARRAYS	2275.00	0.00	40.00	0.00	0.	0.	0.
503	HUB MODULE	366.00	0.00	0.00	0.00	.1000000E+08	.9300000E+07	.1040000E+08
505	CONTROL MOD	12000.00	-375.00	0.00	0.00	.3120000E+08	.2801000E+08	.3115000E+08
506	RMS+TURRET	2336.00	0.00	-127.00	0.00	0.	0.	0.
508	30M RADIO	38600.00	0.00	-454.00	964.00	.5727100E+10	.5471500E+10	.3503400E+10
CONF. 505	TOTAL	58689.00	-76.68	-303.89	634.03	.2088841E+11	.1939105E+11	.7470295E+10
						SL-FT2	SL-FT2	SL-FT2
						.4508557E+07	.4185367E+07	.1612389E+07
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		26616.33	-1.95	-7.72	16.10	.6112800E+07	.5674611E+07	.2186112E+07

E CONST BASE OPTION L+ DA KASULKA 19JAN77 PAGE A 6

TABLE 6 (2/2)

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 505

WEIGHT	58669.00 LBMASS		26616.33 KGMS
H-ARM	-76.68 INCHES		-1.95 METERS
V-ARM	-303.89 INCHES		-7.72 METERS
L-ARM	634.03 INCHES		16.10 METERS
ROLL MOI	.2088841E+11 LB/IN2	.4508557E+07 SL-FT2	.6112800E+07 KG-M2
YAW MOI	.1939105E+11 LB/IN2	.4185367E+07 SL-FT2	.5674611E+07 KG-M2
PITCH MOI	.7470295E+10 LB/IN2	.1612389E+07 SL-FT2	.2186112E+07 KG-M2
ROLL POI	-.5585757E+10 LB/IN2	-.1205630E+07 SL-FT2	-.1634620E+07 KG-M2
YAW POI	.2853121E+10 LB/IN2	.6158176E+06 SL-FT2	.8349392E+06 KG-M2
PITCH POI	-.1367492E+10 LB/IN2	-.2951597E+06 SL-FT2	-.4001839E+06 KG-M2

PRINCIPAL MOI 1	.2177466E+11 LB/IN2	.4699844E+07 SL-FT2	.6372151E+07 KG-M2
DIRECTION COSINES	COSH= .6142102E+00	COSV= .7688682E+00	COSL= .1777287E+00
PRINCIPAL ANGLES	FROM +H= 52.11 DEG	FROM +V= 39.75 DEG	FROM +L= 79.76 DEG
PRINCIPAL MOI 2	.4648557E+10 LB/IN2	.1003347E+07 SL-FT2	.1360360E+07 KG-M2
DIRECTION COSINES	COSH= .1908038E+00	COSV= -.3632274E+00	COSL= .9119538E+00
PRINCIPAL ANGLES	FROM +H= 79.00 DEG	FROM +V=111.30 DEG	FROM +L= 24.22 DEG
PRINCIPAL MOI 3	.2132654E+11 LB/IN2	.4603122E+07 SL-FT2	.6241013E+07 KG-M2
DIRECTION COSINES	COSH= .7657283E+00	COSV= -.5262200E+00	COSL= -.3698010E+00
PRINCIPAL ANGLES	FROM +H= 40.03 DEG	FROM +V=121.75 DEG	FROM +L=111.70 DEG

DESATURATION COEF. = .7543550E+02 (IPMAX+IPMID)/2 = .2155060E+11 LB/IN2, .4651483E+07 SL-FT2

E CONST BASE OPTION L+ DA KASULKA 19JAN77 PAGE C 4

Table 7

SCB (L') SHUTTLE TENDED-DIRECT GROWTH
MASS PROPERTIES STEPS

Table Number	Configuration Number	Description
8	101	Core module with Orbiter adapter
9	102	101 plus power module
10	108	102 plus SC support module and mobile crane
11	109	108 plus strongback and 30m radiometer
12	201	101 plus Orbiter berthed (+Z)
13	202	102 plus Orbiter berthed (+Z)
14	206	108 plus Orbiter berthed (+Z)
15	209	109 plus Orbiter berthed (+Z)

H255 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 8

ITEM DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12 CORE 50FT E1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
23 CRB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
CONF. 101 TOTAL	34900.00	289.00	0.00	0.00	.9522000E+08	.5264649E+09	.5264649E+09
					SL-FT2	SL-FT2	SL-FT2
					.2055229E+05	.1136322E+06	.1136322E+06
	KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
	15827.66	7.34	0.00	0.00	.2786524E+05	.1540650E+06	.1540650E+06

SCB L* TENDED-DIRECT GROWTH DA KASULKA 01FEB77 PAGE A 2

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 9

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE 5UFT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
23	ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR BOOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
CONF. 102	TOTAL	63200.00	562.59	0.00	0.00	.6905104E+10	.1365607E+11	.6856764E+10
						SL-FT2	SL-FT2	SL-FT2
						.1490398E+07	.2947526E+07	.1480396E+07
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		28662.13	14.29	0.00	0.00	.2020714E+07	.3996323E+07	.2007153E+07

SCE L* TENDED-DIRECT GROWTH DA KASULKA 01FEB77 PAGE A 3

MCDONNELL DOUGLAS

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 10 (1/2)

ITEM DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12 CORE 50FT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
23 ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26 PRP BOOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28 ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
30 CRANE	3500.00	1680.00	-130.00	0.00	-0.	-0.	-0.
31 ORB ADPT =2	1200.00	1820.00	0.00	0.00	-0.	-0.	-0.
32 FAB MODULE	31000.00	1500.00	0.00	0.00	.2897900E+09	.1182400E+10	.1182400E+10
CONF. 108 TOTAL	98900.00	911.22	-4.60	0.00	.7251951E+10	.3632592E+11	.2958567E+11
					SL-FT2	SL-FT2	SL-FT2
					.1565262E+07	.7840590E+07	.6385773E+07
	KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
	44852.61	23.15	-.12	0.00	.2122216E+07	.1063044E+08	.8657970E+07

SCB L, TENDED-DIRECT GROWTH DA KASULKA 01FEB77 PAGE A 4

F253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 108

TABLE 10 (2/2)

WEIGHT	98900.00 LBMASS		44852.61 KGMS
H-ARM	911.22 INCHES		23.15 METERS
V-ARM	-4.60 INCHES		-.12 METERS
L-ARM	0.00 INCHES		0.00 METERS
ROLL MOI	.7251951E+10 LB/IN2	.1565262E+07 SL-FT2	.2122216E+07 KG-M2
YAW MOI	.3632592E+11 LB/IN2	.7840590E+07 SL-FT2	.1063044E+08 KG-M2
PITCH MOI	.2958567E+11 LB/IN2	.6385773E+07 SL-FT2	.8657970E+07 KG-M2
ROLL POI	0. LB/IN2	0. SL-FT2	0. KG-M2
YAW POI	0. LB/IN2	0. SL-FT2	0. KG-M2
PITCH POI	-.3497933E+09 LB/IN2	-.7549942E+05 SL-FT2	-.1023638E+06 KG-M2

PRINCIPAL MOI 1	.3633013E+11 LB/IN2	.7841498E+07 SL-FT2	.1063167E+08 KG-M2
DIRECTION COSINES	COSH= .1202954E-01	COSV= .9999277E+00	COSL= .2285540E-58
PRINCIPAL ANGLES	FROM +H= 89.31 DEG	FROM +V= .69 DEG	FROM +L= 90.00 DEG
PRINCIPAL MOI 2	.7247743E+10 LB/IN2	.1564353E+07 SL-FT2	.2120984E+07 KG-M2
DIRECTION COSINES	COSH= .9999277E+00	COSV= -.1202854E-01	COSL= -.1312139E-60
PRINCIPAL ANGLES	FROM +H= .69 DEG	FROM +V= 90.69 DEG	FROM +L= 90.00 DEG
PRINCIPAL MOI 3	.2958567E+11 LB/IN2	.6385773E+07 SL-FT2	.8657970E+07 KG-M2
DIRECTION COSINES	COSH= .1326001E-59	COSV= .6540633E-58	COSL= .1000000E+01
PRINCIPAL ANGLES	FROM +H= 90.00 DEG	FROM +V= 90.00 DEG	FROM +L= 0.00 DEG

DESATURATION COEF. = .7624080E+01 (IPMAX+IPMID)/2 = .3295790E+11 LB/IN2, .7113635E+07 SL-FT2

SCB L+ TENDED-DIRECT GROWTH DA KASULKA 01FEB77 PAGE C 1

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 11 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE 50FT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
23	ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR BOOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
30	CRANE	3500.00	1580.00	-130.00	0.00	-0.	-0.	-0.
31	ORB ADPT =2	1200.00	1820.00	0.00	0.00	-0.	-0.	-0.
32	FAB MODULE	31000.00	1500.00	0.00	0.00	.2697900E+09	.1182400E+10	.1182400E+10
63	RADIOMET 30M	38600.00	2200.00	-240.10	0.00	.5471500E+10	.3503400E+10	.5727100E+10
68	STRONG BACK	4000.00	2100.00	30.00	0.00	.4000000E+08	.2000000E+09	.2000000E+09
CONF. 109	TOTAL	141500.00	1296.40	-67.86	0.00	.1434266E+11	.8880194E+11	.8586460E+11
						SL-FT2	SL-FT2	SL-FT2
						.3095721E+07	.1916702E+08	.1853302E+08
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		64172.34	32.93	-1.72	0.00	.4197246E+07	.2598706E+08	.2512747E+08

SCB L. TENDED-DIRECT GROWTH DA KASULKA 01FEB77

H053 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 139

TABLE 11 (2/2)

WEIGHT	141500.00 LBMASS				64172.34 KGMS	
H-ARM	1296.40 INCHES				32.93 METERS	
V-ARM	-67.80 INCHES				-1.72 METERS	
L-ARM	0.00 INCHES				0.00 METERS	
ROLL MOI	.1434266E+11	LB/IN2	.3095721E+07	SL-FT2	.4197246E+07	KG-M2
YAW MOI	.8880194E+11	LB/IN2	.1916702E+08	SL-FT2	.2598706E+08	KG-M2
PITCH MOI	.8586460E+11	LB/IN2	.1853302E+08	SL-FT2	.2512747E+08	KG-M2
ROLL POI	0.	LB/IN2	0.	SL-FT2	0.	KG-M2
YAW POI	0.	LB/IN2	0.	SL-FT2	0.	KG-M2
PITCH POI	-.8452585E+10	LB/IN2	-.1824407E+07	SL-FT2	-.2473570E+07	KG-M2

PRINCIPAL MOI 1	.8974942E+11 LB/IN2	.1937152E+08 SL-FT2	.2626433E+08 KG-M2
DIRECTION COSINES	COSH= .1113956E+00	COSV= .9937761E+00	COSL= .2314313E-55
PRINCIPAL ANGLES	FROM +H= 83.60 DEG	FROM +V= 6.40 DEG	FROM +L= 90.00 DEG
PRINCIPAL MOI 2	.1339518E+11 LB/IN2	.2891218E+07 SL-FT2	.3919976E+07 KG-M2
DIRECTION COSINES	COSH= .9937761E+00	COSV= -.1113956E+00	COSL= -.1407899E-64
PRINCIPAL ANGLES	FROM +H= 6.40 DEG	FROM +V= 96.40 DEG	FROM +L= 90.00 DEG
PRINCIPAL MOI 3	.8586460E+11 LB/IN2	.1853302E+08 SL-FT2	.2512747E+08 KG-M2
DIRECTION COSINES	COSH= .3118583E-56	COSV= .2781945E-55	COSL= .1000000E+01
PRINCIPAL ANGLES	FROM +H= 90.00 DEG	FROM +V= 90.00 DEG	FROM +L= 0.00 DEG

DESATURATION COEF. = .3830902E+02 (IPMAX+IPMID)/2 = .8780701E+11 LB/IN2, .1895227E+08 SL-FT2

SCB EXTENDED-DIRECT GROWTH DA KASULKA 01FEB77 PAGE C 2

M255 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 12 (1/2)

ITEM DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12 CORE 50FT =1	33701.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4278100E+09
23 ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
50 SHUTTLE +Z	200000.00	-159.00	-493.00	-.40	.3007900E+11	.3962700E+10	.2681800E+11
CONF. 201 TOTAL	234900.00	-92.44	-419.75	-.34	.3739637E+11	.1041297E+11	.4252041E+11
					SL-FT2	SL-FT2	SL-FT2
					.8071635E+07	.2247536E+07	.9179766E+07

SPACE CONSTRUCTION BASE OPTION-L DA KASULKA 17DEC76 PAGE A 1

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 201

TABLE 12 (2/2)

WEIGHT	234900.00 LBMASS					
H-ARM	-92.44 INCHES					
V-ARM	-419.75 INCHES					
L-ARM	-.34 INCHES					
ROLL MOI	.3739637E+11 LB/IN2	.8071635E+07 SL-FT2				
YAW MOI	.1041297E+11 LB/IN2	.2247536E+07 SL-FT2				
PITCH MOI	.4253041E+11 LB/IN2	.9179766E+07 SL-FT2				
ROLL POI	.5859753E+07 LB/IN2	.1264770E+04 SL-FT2				
YAW POI	.5324853E+07 LB/IN2	.1149317E+04 SL-FT2				
PITCH POI	.6562881E+10 LB/IN2	.1416533E+07 SL-FT2				
PRINCIPAL MOI 1	.4253041E+11 LB/IN2	.9179767E+07 SL-FT2				
DIRECTION COSINES	COSH=	-.1088185E-02	COSV=	.3991229E-04	COSL=	.9999994E+00
PRINCIPAL ANGLES	FROM +H= 90.06 DEG		FROM +V= 90.00 DEG		FROM +L=	.06 DEG
PRINCIPAL MOI 2	.8901420E+10 LB/IN2	.1921283E+07 SL-FT2				
DIRECTION COSINES	COSH=	.2244414E+00	CCSV=	.9744876E+00	COSL=	.2053399E-03
PRINCIPAL ANGLES	FROM +H= 77.03 DEG		FROM +V= 12.97 DEG		FROM +L= 89.99 DEG	
PRINCIPAL MOI 3	.3890791E+11 LB/IN2	.8397866E+07 SL-FT2				
DIRECTION COSINES	COSH=	.9744570E+00	CCSV=	-.2244415E+00	COSL=	.1069381E-02
PRINCIPAL ANGLES	FROM +H= 12.97 DEG		FROM +V=102.97 DEG		FROM +L= 89.94 DEG	

DESATURATION COEF. = .1756672E+02 (IPMAX+IPMID)/2 = .4071916E+11 LB/IN2. .8788827E+07 SL-FT2

SPACE CONSTRUCTION BASE OPTIONAL DA KASULKA 17DEC76 PAGE C 1

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 13 (1/2)

ITEM DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
[illegible] CORE 50FT E1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
13 ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
[illegible] PWR BOOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
[illegible] ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
[illegible] SHUTTLE +Z	200000.00	-159.00	-493.00	-.40	.3007900E+11	.3922700E+10	.2881800E+11
CONF. 202 TOTAL	263200.00	14.27	-374.62	-.30	.4865637E+11	.4258501E+11	.7235525E+11
					SL-FT2	SL-FT2	SL-FT2
					.1050200E+08	.9191551E+07	.1561716E+08
	KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
	119365.08	.36	-9.52	-.01	.1423883E+08	.1246211E+08	.2117409E+08

S:B L+ TENDED-DIRECT GROWTH DA KASULKA 01FEB77 PAGE A 1

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 202

TABLE 13 (2/2)

WEIGHT	263200.00 LBMASS		119365.08 KGMS
H-ARM	14.27 INCHES		.36 METERS
V-ARM	-374.62 INCHES		-9.52 METERS
L-ARM	-.30 INCHES		-.01 METERS
ROLL MOI	.4865637E+11 LB/IN2	.1050200E+08 SL-FT2	.1423883E+08 KG-M2
YAW MOI	.4258501E+11 LB/IN2	.9191551E+07 SL-FT2	.1246211E+08 KG-M2
PITCH MOI	.7235525E+11 LB/IN2	.1561716E+08 SL-FT2	.2117409E+08 KG-M2
ROLL POI	.9470395E+07 LB/IN2	.2044091E+04 SL-FT2	.2771423E+04 KG-M2
YAW POI	.1386164E+08 LB/IN2	.2991898E+04 SL-FT2	.4056480E+04 KG-M2
PITCH POI	.1708447E+11 LB/IN2	.3687514E+07 SL-FT2	.4999612E+07 KG-M2

PRINCIPAL MOI 1	.7235526E+11 LB/IN2	.1561716E+08 SL-FT2	.2117409E+08 KG-M2
DIRECTION COSINES	COSH= -.6064844E-03	COSV= .2993167E-04	COSL= .9999998E+00
PRINCIPAL ANGLES	FROM +H= 90.03 DEG	FROM +V= 90.00 DEG	FROM +L= .03 DEG
PRINCIPAL MOI 2	.2826861E+11 LB/IN2	.6101498E+07 SL-FT2	.8272544E+07 KG-M2
DIRECTION COSINES	COSH= .6422825E+00	COSV= .7664679E+00	COSL= .3665927E-03
PRINCIPAL ANGLES	FROM +H= 50.04 DEG	FROM +V= 39.96 DEG	FROM +L= 89.98 DEG
PRINCIPAL MOI 3	.6297277E+11 LB/IN2	.1359205E+08 SL-FT2	.1842839E+08 KG-M2
DIRECTION COSINES	COSH= .7664678E+00	COSV= -.6422826E+00	COSL= .4840754E-03
PRINCIPAL ANGLES	FROM +H= 39.96 DEG	FROM +V=129.96 DEG	FROM +L= 89.97 DEG

DESATURATION COEF. = .8397640E+01 (IPMAX+IPMID)/2 = .6766401E+11 LB/IN2. .1460461E+08 SL-FT2

SCB L' TENDED-DIRECT GROWTH DA KASULKA 01FEB77 PAGE C 1

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 14 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE 50FT #1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
23	CRW ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR ROOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
30	CRANE	3500.00	1680.00	-130.00	0.00	-0.	-0.	-0.
31	CRW ADPT #2	1200.00	1820.00	0.00	0.00	-0.	-0.	-0.
32	FAB MODULE	31000.00	1500.00	0.00	0.00	.2897900E+09	.1182400E+10	.1182400E+10
50	SHUTTLE +Z	200000.00	-159.00	-493.00	-.40	.3007900E+11	.3922700E+10	.2881800E+11
CONF. 206	TOTAL	298900.00	195.12	-331.40	-.27	.5311618E+11	.1160452E+12	.1499854E+12
						SL-FT2	SL-FT2	SL-FT2
						.1146460E+08	.2504720E+08	.3237286E+08
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		135555.56	4.96	-8.42	-.01	.1554395E+08	.3395953E+08	.4389163E+08

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 206

TABLE 14 (2/2)

WEIGHT	298900.00 LBMASS		135555.56 KGMS
H-ARM	195.12 INCHES		4.96 METERS
V-ARM	-331.40 INCHES		-8.42 METERS
L-ARM	-.27 INCHES		-.01 METERS
ROLL MOI	.5311618E+11 LB/IN2	.1146460E+08 SL-FT2	.1554395E+08 KG-M2
YAW MOI	.1160452E+12 LB/IN2	.2504720E+08 SL-FT2	.3395953E+08 KG-M2
PITCH MOI	.1499854E+12 LB/IN2	.3237286E+08 SL-FT2	.4389183E+08 KG-M2
ROLL POI	.1292812E+08 LB/IN2	.2790407E+04 SL-FT2	.3783295E+04 KG-M2
YAW POI	.2832973E+08 LB/IN2	.6114584E+04 SL-FT2	.8290286E+04 KG-M2
PITCH POI	.3424016E+11 LB/IN2	.7390398E+07 SL-FT2	.1002006E+08 KG-M2

PRINCIPAL MOI 1	.1499854E+12 LB/IN2	.3237286E+08 SL-FT2	.4389183E+08 KG-M2
DIRECTION COSINES	COSH= -.2452708E-03	COSV= -.1334702E-03	COSL= .1000000E+01
PRINCIPAL ANGLES	FROM +H= 90.01 DEG	FROM +V= 90.01 DEG	FROM +L= .02 DEG
PRINCIPAL MOI 2	.3807902E+11 LB/IN2	.8218979E+07 SL-FT2	.1114347E+08 KG-M2
DIRECTION COSINES	COSH= .9155959E+00	COSV= .4020996E+00	COSL= .2782372E-03
PRINCIPAL ANGLES	FROM +H= 23.71 DEG	FROM +V= 66.29 DEG	FROM +L= 89.98 DEG
PRINCIPAL MOI 3	.1310823E+12 LB/IN2	.2829282E+08 SL-FT2	.3836002E+08 KG-M2
DIRECTION COSINES	COSH= -.4020996E+00	COSV= .9155959E+00	COSL= .2358147E-04
PRINCIPAL ANGLES	FROM +H=113.71 DEG	FROM +V= 23.71 DEG	FROM +L= 90.00 DEG

DESATURATION COEF. = .1084000E+02 (IPMAX+IPMID)/2 = .1405339E+12 LB/IN2, .3033284E+08 SL-FT2

SCB L. TENDED-DIRECT GROWTH DA KASULKA 01FEB77 PAGE C 3

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 15 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE 50FT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
23	ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR BOOM	18300.00	900.00	0.00	0.00	.1256400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
30	CRANE	3500.00	1680.00	-130.00	0.00	-0.	-0.	-0.
31	ORB ADPT =2	1200.00	1520.00	0.00	0.00	-0.	-0.	-0.
32	FAB MODULE	31000.00	1500.00	0.00	0.00	.2897900E+09	.1182400E+10	.1182400E+10
50	SHUTTLE +Z	200000.00	-159.00	-493.00	-.40	.3007900E+11	.3922700E+10	.2881800E+11
63	RAT ICMET 30M	38600.00	2200.00	-240.10	0.00	.5471500E+10	.3503400E+10	.5727100E+10
68	STRONG BACK	4000.00	2100.00	30.00	0.00	.4000000E+08	.2000000E+09	.2000000E+09
COMP. 209	TOTAL	341500.00	444.04	-316.85	-.23	.5939954E+11	.2682573E+12	.3051931E+12
						SL-FT2	SL-FT2	SL-FT2
						.1282080E+08	.5790068E+08	.6587291E+08
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		154075.28	11.26	-8.05	-.01	.1738272E+08	.7650300E+08	.8931192E+08

SCR L* TENDED-DIRECT GROWTH DA KASULKA 01FEB77

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 239

TABLE 15 (2/2)

WEIGHT	341500.00 LBMASS		154875.28 KGMS
H-ARM	444.04 INCHES		11.28 METERS
V-ARM	-316.85 INCHES		-8.05 METERS
L-ARM	-.23 INCHES		-.01 METERS
ROLL MOI	.5939954E+11 LB/IN2	.1282080E+08 SL-FT2	.1738272E+08 KG-M2
YAW MOI	.2682573E+12 LB/IN2	.5790068E+08 SL-FT2	.7850300E+08 KG-M2
PITCH MOI	.3051931E+12 LB/IN2	.6587291E+08 SL-FT2	.8931192E+08 KG-M2
ROLL POI	.1409233E+08 LB/IN2	.3041690E+04 SL-FT2	.4123989E+04 KG-M2
YAW POI	.4824328E+06 LB/IN2	.1041283E+05 SL-FT2	.1411795E+05 KG-M2
PITCH POI	.4282221E+11 LB/IN2	.9242750E+07 SL-FT2	.1253152E+08 KG-M2
PRINCIPAL MOI 1	.3051931E+12 LB/IN2	.6587291E+08 SL-FT2	.8931193E+08 KG-M2
DIRECTION COSINES	COSH= -.1626591E-03	COSV= -.1929538E-03	COSL= .1000000E+01
PRINCIPAL ANGLES	FROM +H= 90.01 DEG	FROM +V= 90.01 DEG	FROM +L= .01 DEG
PRINCIPAL MOI 2	.5096065E+11 LB/IN2	.1099935E+08 SL-FT2	.1491316E+08 KG-M2
DIRECTION COSINES	COSH= .9811300E+00	COSV= .1933493E+00	COSL= .1968972E-03
PRINCIPAL ANGLES	FROM +H= 11.15 DEG	FROM +V= 78.85 DEG	FROM +L= 89.99 DEG
PRINCIPAL MOI 3	.2766962E+12 LB/IN2	.5972213E+06 SL-FT2	.8097256E+08 KG-M2
DIRECTION COSINES	COSH= -.1933493E+00	COSV= .9811300E+00	COSL= .1578627E-03
PRINCIPAL ANGLES	FROM +H=101.15 DEG	FROM +V= 11.15 DEG	FROM +L= 89.99 DEG

DESATURATION COEF. = .1664279E+02   (IPMAX+IPMID)/2 = .2909447E+12 LB/IN2,   .6279752E+08 SL-FT2

SCB L+ TENDED-DIRECT GROWTH   DA KASULKA 01FEB77   PAGE C 4

Table 16

SCB (L) PERMANENTLY MANNED-DIRECT GROWTH
MASS PROPERTIES STEPS

Table Number	Configuration Number	Description
17	120	Core module with Orbiter adapter
18	121	120 plus power module
19	221	121 plus Orbiter berthed (+Z)
20	122	121 plus crew support module
21	222	122 plus Orbiter berthed (+Z)
22	123	122 plus hab/control module
23	223	123 plus Orbiter berthed (+Z)
24	124	123 plus logistic module
25	224	124 plus Orbiter berthed (+Z)
26	125	124 plus mobile crane and SC support module
27	225	125 plus Orbiter berthed (+Z)
28	226	125 plus Orbiter berthed (-Z)
29	227	125 plus Orbiter berthed (+Y)
30	128	125 plus universal truss assy jig, composite fabrication unit, and strongback
31	228	128 plus Orbiter berthed (+Z)
32	129	128 plus 30m radiometer
33	229	129 plus Orbiter berthed (+Z)
34	130	128 plus MBL antenna
35	230	130 plus Orbiter berthed (+Z)
36	131	128 plus TA-2
37	231	131 plus Orbiter berthed (+Z)

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 17

ITEM DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12 CORE 50FT 31	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
23 ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
CONF. 120 TOTAL	34900.00	289.00	0.00	0.00	.9522000E+08	.5264649E+09	.5264649E+09
					SL-FT2	SL-FT2	SL-FT2
					.2055229E+05	.1136322E+06	.1136322E+06
	KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
	15827.66	7.34	0.00	0.00	.2786524E+05	.1540650E+06	.1540650E+06

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE A 2

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 18

ITEM DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12 CORE 50FT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
23 ORB ADAPTER	1201.00	-20.00	0.00	0.00	-0.	-0.	-0.
26 PWR BOOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28 ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
CONF. 121 TOTAL	63200.00	562.59	0.00	0.00	.6905104E+10	.1365607E+11	.6855764E+10
					SL-FT2	SL-FT2	SL-FT2
					.1490398E+07	.2947528E+07	.1480396E+07
	KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
	28662.13	14.29	0.00	0.00	.2020714E+07	.3996323E+07	.2007153E+07

SCB L PERMAN-MANNED DIRECT GROWTH CA KASULKA 2FE377

PAGE A 3

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 19 (1/2)

ITEM DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12 CORE 50FT E1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
23 ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26 PWR BOOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28 ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
50 SHUTTLE +Z	200000.00	-159.00	-493.00	-.40	.3007900E+11	.3922700E+10	.2881800E+11
CONF. 221 TOTAL	263200.00	14.27	-374.62	-.30	.4665637E+11	.4258501E+11	.7235525E+11
					SL-FT2	SL-FT2	SL-FT2
					.1050200E+08	.9191551E+07	.1561716E+08
	KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
	119365.08	.36	-9.52	-.01	.1423883E+08	.1246211E+08	.2117409E+08

SCB L FERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

PAGE A 4

HE53 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 221

TABLE 19 (2/2)

WEIGHT	263200.00 LBMASS		119365.08 KGMS	
H-ARM	14.27 INCHES		.36 METERS	
V-ARM	-374.62 INCHES		-9.52 METERS	
L-ARM	-.30 INCHES		-.01 METERS	
ROLL MOI	.4865637E+11 LB/IN2	.1150200E+08 SL-FT2	.1423883E+08 KG-M2	
YAW MOI	.4258501E+11 LB/IN2	.9191551E+07 SL-FT2	.1246211E+08 KG-M2	
PITCH MOI	.7235525E+11 LB/IN2	.1561716E+08 SL-FT2	.2117409E+08 KG-M2	
ROLL POI	.9470395E+07 LB/IN2	.2044091E+04 SL-FT2	.2771423E+04 KG-M2	
YAW POI	.1386164E+08 LB/IN2	.2991698E+04 SL-FT2	.4056480E+04 KG-M2	
PITCH POI	.1708447E+11 LB/IN2	.3687514E+07 SL-FT2	.4999612E+07 KG-M2	
PRINCIPAL MOI 1	.7235526E+11 LB/IN2	.1561716E+08 SL-FT2	.2117409E+08 KG-M2	
DIRECTION COSINES	COSH= -.6064544E-03	COSV= .2993167E-04	COSL= .9999998E+00	
PRINCIPAL ANGLES	FROM +H= 90.03 DEG	FROM +V= 90.00 DEG	FROM +L= .03 DEG	
PRINCIPAL MOI 2	.2826861E+11 LB/IN2	.6101498E+07 SL-FT2	.6272544E+07 KG-M2	
DIRECTION COSINES	COSH= .6422825E+00	COSV= .7664679E+00	COSL= .3665927E-03	
PRINCIPAL ANGLES	FROM +H= 50.04 DEG	FROM +V= 39.96 DEG	FROM +L= 89.98 DEG	
PRINCIPAL MOI 3	.6297277E+11 LB/IN2	.1359205E+08 SL-FT2	.1842839E+08 KG-M2	
DIRECTION COSINES	COSH= .7664678E+00	COSV= -.6422826E+00	COSL= .4840754E-03	
PRINCIPAL ANGLES	FROM +H= 39.95 DEG	FROM +V=129.96 DEG	FROM +L= 89.97 DEG	
DESATURATION COEF. = .8397640E+01		(IPMAX+IPMID)/2 =	.6766401E+11 LB/IN2.	.1460461E+08 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 20 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE SOFT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
19	CREW SUPT MO	29100.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR BOOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	960.00	0.00	0.00	.2797300E+10	.7144000E+10	.3466900E+09
CONF. 122	TOTAL	92300.00	536.55	0.00	119.80	.1018188E+11	.1706878E+11	.7151344E+10
						SL-FT2	SL-FT2	SL-FT2
						.2197658E+07	.3684127E+07	.1543547E+07
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		41859.41	13.63	0.00	3.04	.2979632E+07	.4995020E+07	.2092774E+07

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

PAGE A 5

MCDONNELL DOUGLAS

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 122

TABLE 20 (2/2)

WEIGHT	92300.00	LBMASS			41859.41	KGMS
H-ARM	536.55	INCHES			13.63	METERS
V-ARM	0.00	INCHES			0.00	METERS
L-ARM	119.60	INCHES			3.04	METERS
ROLL MOI	.1018186E+11	LB/IN2	.2197658E+07	SL-FT2	.2979632E+07	KG-M2
YAW MOI	.1700878E+11	LB/IN2	.3684127E+07	SL-FT2	.4995020E+07	KG-M2
PITCH MOI	.7151344E+10	LB/IN2	.1543547E+07	SL-FT2	.2092774E+07	KG-M2
ROLL POI	0.	LB/IN2	0.	SL-FT2	0.	KG-M2
YAW POI	-.6253820E+09	LB/IN2	-.1349625E+06	SL-FT2	-.1830122E+06	KG-M2
PITCH POI	0.	LB/IN2	0.	SL-FT2	0.	KG-M2
PRINCIPAL MOI 1	.1700878E+11	LB/IN2	.3684127E+07	SL-FT2	.4995020E+07	KG-M2

DIRECTION COSINES	COSH= .5673389-109	COSV= .1000000E+01	COSL= .7021093-109
PRINCIPAL ANGLES	FROM +H= 90.00 DEG	FROM +V= 0.00 DEG	FROM +L= 90.00 DEG

PRINCIPAL MOI 2	.7027363E+10	LB/IN2	.1516786E+07	SL-FT2	.2056492E+07	KG-M2

DIRECTION COSINES	COSH= -.1944549E+00	COSV= -.9150021-110	COSL= .9809095E+00
PRINCIPAL ANGLES	FROM +H=101.21 DEG	FROM +V= 90.00 DEG	FROM +L= 11.21 DEG

PRINCIPAL MOI 3	.1030586E+11	LB/IN2	.2224418E+07	SL-FT2	.3015914E+07	KG-M2

DIRECTION COSINES	COSH= .9809095E+00	COSV= .4079837-112	COSL= .1944649E+00
PRINCIPAL ANGLES	FROM +H= 11.21 DEG	FROM +V= 90.00 DEG	FROM +L= 78.79 DEG

DESATURATION COEF. = .1969552E+01 (IPMAX+IPMID)/2 = .1368732E+11 LB/IN2. .2954272E+07 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE C 2

ORIGINAL PAGE IS OF POOR QUALITY

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 21 (1/2)

ITEM DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12 CORE SUPT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
19 CREW SUPT MO	29100.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23 CRG ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26 PWR BOOM	16300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28 ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
50 SHUTTLE +Z	200000.00	-159.00	-493.00	-.40	.3007900E+11	.3922700E+10	.2881800E+11
CONF. 222 TOTAL	292300.00	60.64	-337.32	37.56	.5652300E+11	.5245783E+11	.8187275E+11
					SL-FT2	SL-FT2	SL-FT2
					.1219993E+08	.1132250E+08	.1767142E+08
	KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
	132562.36	1.54	-8.57	.95	.1654093E+08	.1535129E+08	.2395930E+08

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

PAGE A 6

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 222

TABLE 21 (2/2)

WEIGHT	292300.00 LBMASS		132562.36 KGMS
H-ARM	60.64 INCHES		1.54 METERS
V-ARM	-337.32 INCHES		-8.57 METERS
L-ARM	37.50 INCHES		.95 METERS
ROLL MOI	.5652300E+11 LB/IN2	.1219993E+08 SL-FT2	.1654093E+08 KG-M2
YAW MOI	.5245783E+11 LB/IN2	.1132250E+08 SL-FT2	.1535129E+08 KG-M2
PITCH MOI	.8187275E+11 LB/IN2	.1767142E+08 SL-FT2	.2395930E+08 KG-M2
ROLL POI	.3742590E+10 LB/IN2	.8078009E+06 SL-FT2	.1095234E+07 KG-M2
YAW POI	.4654894E+10 LB/IN2	.1004713E+07 SL-FT2	.1362211E+07 KG-M2
PITCH POI	.2165614E+11 LB/IN2	.4674263E+07 SL-FT2	.6337468E+07 KG-M2

PRINCIPAL MOI 1	.8270141E+11 LB/IN2	.1785028E+08 SL-FT2	.2420179E+08 KG-M2	
DIRECTION COSINES	COSH= -.1819761E+00	COSV= .8628048E-02	COSL= .9832651E+00	
PRINCIPAL ANGLES	FROM +H=100.48 DEG	FROM +V= 89.51 DEG	FROM +L= 10.50 DEG	
PRINCIPAL MOI 2	.3203999E+11 LB/IN2	.6915515E+07 SL-FT2	.9376205E+07 KG-M2	
DIRECTION COSINES	COSH= .6703958E+00	COSV= .7326182E+00	COSL= .1176437E+00	
PRINCIPAL ANGLES	FROM +H= 47.90 DEG	FROM +V= 42.89 DEG	FROM +L= 83.24 DEG	
PRINCIPAL MOI 3	.7611218E+11 LB/IN2	.1642806E+08 SL-FT2	.2227352E+08 KG-M2	
DIRECTION COSINES	COSH= .7193429E+00	COSV= -.6805851E+00	COSL= .1391032E+00	
PRINCIPAL ANGLES	FROM +H= 44.00 DEG	FROM +V=132.89 DEG	FROM +L= 82.00 DEG	

DESATURATION COEF. = .1437705E+02 (IPMAX+IPMID)/2 = .7940679E+11 LB/IN2, .1713917E+06 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE C 3

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 22 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE 50FT =1	33700.00	300.00	0.00	0.00	.9522100E+08	.4078100E+09	.4078100E+09
16	HAB/CONT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19	CREW SUPT MO	29100.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR BOOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
CONF. 123	TOTAL	121600.00	494.01	0.00	-.63	.1613710E+11	.2371725E+11	.8001252E+10
						SL-FT2	SL-FT2	SL-FT2
						.3483032E+07	.5119134E+07	.1726991E+07
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		55147.39	12.55	0.00	-.02	.4722371E+07	.6940633E+07	.2341492E+07

SCB L PERMAN-MANNED DIRECT GROWTH OA KASULKA 2FEB77

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 123

TABLE 22 (2|2)

WEIGHT	121600.00	LBMASS			55147.39	KGMS
H-ARM	494.01	INCHES			12.55	METERS
V-ARM	0.00	INCHES			0.00	METERS
L-ARM	-.63	INCHES			-.02	METERS
ROLL MOI	.1613716E+11	LB/IN2	.3483032E+07	SL-FT2	.4722371E+07	KG-M2
YAW MOI	.2371725E+11	LB/IN2	.5119134E+07	SL-FT2	.6940633E+07	KG-M2
PITCH MOI	.8001252E+10	LB/IN2	.1726991E+07	SL-FT2	.2341492E+07	KG-M2
ROLL POI	0.	LB/IN2	0.	SL-FT2	0.	KG-M2
YAW POI	.1337145E+10	LB/IN2	.2886095E+06	SL-FT2	.3913030E+06	KG-M2
PITCH POI	0.	LB/IN2	0.	SL-FT2	0.	KG-M2

PRINCIPAL MOI 1	.2371725E+11 LB/IN2		.5119134E+07 SL-FT2		.6940633E+07 KG-M2	
DIRECTION COSINES	COSH=	.3158658E-60	COSV=	.1000000E+01	COSL=	-.3196093E-61
PRINCIPAL ANGLES	FROM +H=	90.00 DEG	FROM +V=	0.00 DEG	FROM +L=	90.00 DEG
PRINCIPAL MOI 2	.7787124E+10 LB/IN2		.1680773E+07 SL-FT2		.2278829E+07 KG-M2	
DIRECTION COSINES	COSH=	.1581230E+00	COSV=	.5490813E-61	COSL=	.9874194E+00
PRINCIPAL ANGLES	FROM +H=	80.90 DEG	FROM +V=	90.00 DEG	FROM +L=	9.10 DEG
PRINCIPAL MOI 3	.1635122E+11 LB/IN2		.3529249E+07 SL-FT2		.4785033E+07 KG-M2	
DIRECTION COSINES	COSH=	.9874194E+00	COSV=	.4207428E-59	COSL=	-.1581230E+00
PRINCIPAL ANGLES	FROM +H=	9.10 DEG	FROM +V=	90.00 DEG	FROM +L=	99.10 DEG

DESATURATION COEF. = .3325296E+01 (IPMAX+IPMID)/2 = .2003424E+11 LB/IN2, .4324192E+07 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE C 4

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H252 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 23 (1/2)

ITEM DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	Y/W MOI	PITCH MOI
12 CORE 50FT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
16 HAB/CONT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19 CREW SUPT MO	29100.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23 ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26 PWR ROOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28 ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
50 SHUTTLE +Z	200000.00	-159.00	-493.00	-.40	.3007900E+11	.3922700E+10	.2881800E+11
CONF. 223 TOTAL	321600.00	87.91	-306.59	-.49	.6459593E+11	.5988711E+11	.8744623E+11
					SL-FT2	SL-FT2	SL-FT2
					.1394239E+08	.1292604E+08	.1887440E+08
	KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
	145150.34	2.23	-7.79	-.01	.1890339E+08	.1752540E+08	.2559032E+08

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

MPS PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 223

TABLE 23 (2/2)

WEIGHT	321600.00 L-MASS		145850.34 KGMS
H-ARM	87.91 INCHES		2.23 METERS
V-ARM	-306.59 INCHES		-7.79 METERS
L-ARM	-.49 INCHES		-.01 METERS
ROLL MOI	.6459593E+11 LB/IN2	.1394239E+08 SL-FT2	.1890339E+08 KG-M2
YAW MOI	.5980711E+11 LB/IN2	.1292604E+08 SL-FT2	.1752540E+08 KG-M2
PITCH MOI	.8744623E+11 LB/IN2	.1887440E+08 SL-FT2	.2559032E+08 KG-M2
ROLL POI	-.8388358E+07 LB/IN2	-.1810544E+04 SL-FT2	-.2454775E+04 KG-M2
YAW POI	.1326034E+10 LB/IN2	.2862113E+06 SL-FT2	.3880515E+06 KG-M2
PITCH POI	.2434537E+11 LB/IN2	.5254706E+07 SL-FT2	.7124445E+07 KG-M2

PRINCIPAL MOI 1	.8813934E+11 LB/IN2	.1902400E+08 SL-FT2	.2579316E+08 KG-M2
DIRECTION COSINES	COSH= -.4285993E+00	COSV= .3695752E+00	COSL= .8244494E+00
PRINCIPAL ANGLES	FROM +H=115.38 DEG	FROM +V= 68.31 DEG	FROM +L= 34.47 DEG
PRINCIPAL MOI 2	.3776679E+11 LB/IN2	.8151587E+07 SL-FT2	.1105210E+08 KG-M2
DIRECTION COSINES	COSH= .6723724E+00	COSV= .7399985E+00	COSL= .1782189E-01
PRINCIPAL ANGLES	FROM +H= 47.75 DEG	FROM +V= 42.27 DEG	FROM +L= 88.98 DEG
PRINCIPAL MOI 3	.8602313E+11 LB/IN2	.1856724E+08 SL-FT2	.2517387E+08 KG-M2
DIRECTION COSINES	COSH= .6035348E+00	COSV= -.5619755E+00	COSL= .5656549E+00
PRINCIPAL ANGLES	FROM +H= 52.88 DEG	FROM +V=124.19 DEG	FROM +L= 55.55 DEG

DESATURATION COEF. = .4660036E+02 (IPMAX+IPMID)/2 = .8708124E+11 LB/IN2, .1879562E+08 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE C 5

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 24 (1/2)

ITEM DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12 CORE 50FT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
15 LOGISTIC =1	30000.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16 HAB/CONT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19 CREW SUPT MO	29100.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23 CRH ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26 PWR BOOM	18300.00	960.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28 ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
CONF. 124 TOTAL	151600.00	420.00	0.00	74.70	.2002282E+11	.3096910E+11	.1152402E+11
					SL-FT2	SL-FT2	SL-FT2
					.4321727E+07	.6684372E+07	.2487345E+07
	KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
	68752.83	10.67	0.00	1.90	.5659492E+07	.9062817E+07	.3372397E+07

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

PAGE A 9

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 124

TABLE 24 (2/2)

WEIGHT	151600.00 LBMASS				68752.83 KGMS	
H-ARM	420.00 INCHES				10.67 METERS	
V-ARM	0.00 INCHES				0.00 METERS	
L-ARM	74.70 INCHES				1.90 METERS	
ROLL MOI	.2002282E+11 LB/IN2		.4321727E+07 SL-FT2		.5859492E+07 KG-M2	
YAW MOI	.3096910E+11 LB/IN2		.6684372E+07 SL-FT2		.9062817E+07 KG-M2	
PITCH MOI	.1152402E+11 LB/IN2		.2487345E+07 SL-FT2		.3372397E+07 KG-M2	
ROLL POI	0. LB/IN2		0. SL-FT2		0. KG-M2	
YAW POI	-.2068480E+10 LB/IN2		-.4507777E+06 SL-FT2		-.6111742E+06 KG-M2	
PITCH POI	0. LB/IN2		0. SL-FT2		0. KG-M2	
PRINCIPAL MOI 1	.3096910E+11 LB/IN2		.6684372E+07 SL-FT2		.9062817E+07 KG-M2	
DIRECTION COSINES	COSH=	.3113941-109	COSV=	.1000000E+01	COSL=	.9015310-110
PRINCIPAL ANGLES	FROM +H= 90.00 DEG		FROM +V= 0.00 DEG		FROM +L= 90.00 DEG	
PRINCIPAL MOI 2	.1103653E+11 LB/IN2		.2382558E+07 SL-FT2		.3230324E+07 KG-M2	
DIRECTION COSINES	COSH=	-.2264221E+00	COSV=	-.2339859-110	COSL=	.9740293E+00
PRINCIPAL ANGLES	FROM +H=103.09 DEG		FROM +V= 90.00 DEG		FROM +L= 13.09 DEG	
PRINCIPAL MOI 3	.2050631E+11 LB/IN2		.4426514E+07 SL-FT2		.6001565E+07 KG-M2	
DIRECTION COSINES	COSH=	.9740293E+00	COSV=	.1999909-108	COSL=	.2264221E+00
PRINCIPAL ANGLES	FROM +H= 13.09 DEG		FROM +V= 90.00 DEG		FROM +L= 76.91 DEG	

DESATURATION COEF. = .2810527E+01 (IPMAX+IPMID)/2 = .2573870E+11 LB/IN2, .5555443E+07 SL-FT2

SCR L FERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE C 6

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 25 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE SOFT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
15	LOGISTIC =1	30001.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16	HAB/COMT MOD	29301.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19	CREW SUPT MO	29100.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	CRE ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR ROOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
50	SHUTTLE +Z	200000.00	-159.00	-493.00	-.40	.3007900E+11	.3922700E+10	.2881800E+11
CONF. 224	TOTAL	351000.00	90.65	-280.43	31.98	.7154731E+11	.6428741E+11	.9021049E+11
						SL-FT2	SL-FT2	SL-FT2
						.1544276E+08	.1387580E+08	.1947104E+08
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		159455.76	2.30	-7.12	.81	.2093765E+08	.1861311E+08	.2639926E+08

SCR L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

TABLE 25 (2/2)

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 224

WEIGHT	351600.00 LBMASS		159455.78 KGMS
H-ARM	90.65 INCHES		2.30 METERS
V-ARM	-280.43 INCHES		-7.12 METERS
L-ARM	31.98 INCHES		.81 METERS
ROLL MOI	.7154731E+11 LB/IN2	.1544278E+08 SL-FT2	.2093765E+08 KG-M2
YAW MOI	.6428761E+11 LB/IN2	.1387580E+08 SL-FT2	.1881311E+08 KG-M2
PITCH MOI	.9021049E+11 LB/IN2	.1947104E+08 SL-FT2	.2639926E+08 KG-M2
ROLL POI	.3192621E+10 LB/IN2	.6890955E+06 SL-FT2	.9342907E+06 KG-M2
YAW POI	.1661069E+10 LB/IN2	.3585252E+06 SL-FT2	.4860963E+06 KG-M2
PITCH POI	.2461534E+11 LB/IN2	.5312976E+07 SL-FT2	.7203449E+07 KG-M2

PRINCIPAL MOI 1	.9306256E+11 LB/IN2	.2008663E+08 SL-FT2	.2723389E+08 KG-M2
DIRECTION COSINES	COSH= .7073096E+00	COSV= -.6386764E+00	COSL= .3029942E+00
PRINCIPAL ANGLES	FROM +H= 44.95 DEG	FROM +V=129.69 DEG	FROM +L= 72.36 DEG
PRINCIPAL MOI 2	.4277717E+11 LB/IN2	.9233027E+07 SL-FT2	.1251834E+08 KG-M2
DIRECTION COSINES	COSH= .6507953E+00	COSV= .7556724E+00	COSL= .7365269E-01
PRINCIPAL ANGLES	FROM +H= 49.40 DEG	FROM +V= 40.92 DEG	FROM +L= 85.78 DEG
PRINCIPAL MOI 3	.9020548E+11 LB/IN2	.1946996E+08 SL-FT2	.2639779E+08 KG-M2
DIRECTION COSINES	COSH= -.2760046E+00	COSV= .1450920E+00	COSL= .9501420E+00
PRINCIPAL ANGLES	FROM +H=106.02 DEG	FROM +V= 81.66 DEG	FROM +L= 18.17 DEG

DESATURATION COEF. = .3420049E+02 (IPMAX+IPMID)/2 = .9163402E+11 LB/IN2. .1977829E+08 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE C 7

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H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 26 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE 50FT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
15	LOGISTIC =1	30000.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16	HAB/COMT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19	CREW SUPT MO	29100.00	460.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR BOOM	18300.00	900.00	0.00	0.00	.1256400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
30	CRANE	3500.00	1680.00	-130.00	0.00	-0.	-0.	-0.
31	ORB ADPT =2	1200.00	1820.00	0.00	0.00	-0.	-0.	-0.
32	FAP MODULE	31000.00	1500.00	0.00	0.00	.2897900E+09	.1182400E+10	.1182400E+10
CONF. 125	TOTAL	187300.00	631.27	-2.43	60.46	.2053188E+11	.6801995E+11	.4847169E+11
						SL-FT2	SL-FT2	SL-FT2
						.4431602E+07	.1468143E+08	.1046213E+08
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		84943.31	16.03	-.06	1.54	.6008463E+07	.1990540E+08	.1418479E+08

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 125

TABLE 26 (2/2)

WEIGHT	187300.00 LBMASS		84943.31 KGMS
H-ARM	631.27 INCHES		16.03 METERS
V-ARM	-2.43 INCHES		-.06 METERS
L-ARM	60.46 INCHES		1.54 METERS
ROLL MOI	.2053188E+11 LB/IN2	.4431602E+07 SL-FT2	.6008463E+07 KG-M2
YAW MOI	.6801995E+11 LB/IN2	.1468143E+08 SL-FT2	.1990540E+08 KG-M2
PITCH MOI	.4847169E+11 LB/IN2	.1046213E+08 SL-FT2	.1418479E+08 KG-M2
ROLL POI	.2750892E+08 LB/IN2	.5937526E+04 SL-FT2	.8050228E+04 KG-M2
YAW POI	-.4480849E+10 LB/IN2	-.9671467E+06 SL-FT2	-.1311279E+07 KG-M2
PITCH POI	-.4771743E+09 LB/IN2	-.10290[illegible]E+06 SL-FT2	-.1396406E+06 KG-M2
PRINCIPAL MOI 1	.6802476E+11 LB/IN2	.1468247E+08 SL-FT2	.1990681E+08 KG-M2
DIRECTION COSINES	COSH= .1013312E+01	COSV= .9999482E+00	COSL= .9153286E-03
PRINCIPAL ANGLES	FROM +H= 89.42 DEG	FROM +V= .58 DEG	FROM +L= 89.95 DEG
PRINCIPAL MOI 2	.1982616E+11 LB/IN2	.4279279E+07 SL-FT2	.5801940E+07 KG-M2
DIRECTION COSINES	COSH= .9879362E+00	COSV= -.9869925E-02	COSL= -.1545464E+00
PRINCIPAL ANGLES	FROM +H= 8.91 DEG	FROM +V= 90.57 DEG	FROM +L= 98.89 DEG
PRINCIPAL MOI 3	.4917261E+11 LB/IN2	.1061342E+08 SL-FT2	.1438990E+08 KG-M2
DIRECTION COSINES	COSH= .1545294E+00	COSV= -.2470323E-02	COSL= .9879851E+00
PRINCIPAL ANGLES	FROM +H= 81.11 DEG	FROM +V= 90.14 DEG	FROM +L= 8.89 DEG

DESATURATION COEF. = .4113326E+01 (IPMAX+IPMID)/2 = .5859866E+11 LB/IN2, .1264794E+08 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE C 8

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 27 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE 50FT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
15	LOGISTIC =1	30000.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16	HAB/CONT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19	CREW SUPT MO	29100.00	460.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	CRL ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR BOOM	18300.00	900.00	0.00	0.00	.1256400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
30	CRANE	3500.00	1660.00	-230.00	0.00	-0.	-0.	-0.
31	CRL ADPT =2	1200.00	1820.00	0.00	0.00	-0.	-0.	-0.
32	FAB MODULE	31000.00	1500.00	0.00	0.00	.2697900E+09	.1182400E+10	.1182400E+10
50	SHUTTLE +Z	200000.00	-159.00	-493.00	-.40	.3007900E+11	.3922700E+10	.2881800E+11
CONF. 225	TOTAL	387300.00	223.18	-255.76	29.03	.7424593E+11	.1327050E+12	.1609706E+12
						SL-FT2	SL-FT2	SL-FT2
						.1602525E+08	.2864305E+08	.3474390E+08
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		175646.26	5.67	-6.50	.74	.2172738E+08	.3883487E+08	.4710654E+08

SCR L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

MCDONNELL DOUGLAS

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 225

TABLE 27 (2/2)

WEIGHT	387300.00 LBMASS		175646.26 KGMS
H-ARM	223.16 INCHES		5.67 METERS
V-ARM	-255.76 INCHES		-6.50 METERS
L-ARM	29.03 INCHES		.74 METERS
ROLL MOI	.7424593E+11 LB/IN2	.1602525E+08 SL-FT2	.2172736E+08 KG-M2
YAW MOI	.1327050E+12 LB/IN2	.2864305E+08 SL-FT2	.3883467E+08 KG-M2
PITCH MOI	.1609706E+12 LB/IN2	.3474390E+08 SL-FT2	.4710654E+08 KG-M2
ROLL POI	.2915181E+10 LB/IN2	.6292128E+06 SL-FT2	.8531005E+06 KG-M2
YAW POI	.1709309E+09 LB/IN2	.3689375E+05 SL-FT2	.5002134E+05 KG-M2
PITCH POI	.3701968E+11 LB/IN2	.7990331E+07 SL-FT2	.1083346E+08 KG-M2
PRINCIPAL MOI 1	.1615837E+12 LB/IN2	.3487624E+08 SL-FT2	.4728596E+08 KG-M2
DIRECTION COSINES	COSH= .8707453E-01	COSV= -.2099249E+00	COSL= .9738324E+00
PRINCIPAL ANGLES	FROM +H= 85.00 DEG	FROM +V=102.12 DEG	FROM +L= 13.14 DEG
PRINCIPAL MOI 2	.5628802E+11 LB/IN2	.1214921E+08 SL-FT2	.1647216E+08 KG-M2
DIRECTION COSINES	COSH= .8996697E+00	COSV= .4363587E+00	COSL= .1362066E-01
PRINCIPAL ANGLES	FROM +H= 25.89 DEG	FROM +V= 64.13 DEG	FROM +L= 89.22 DEG
PRINCIPAL MOI 3	.1500497E+12 LB/IN2	.3238675E+08 SL-FT2	.4391066E+08 KG-M2
DIRECTION COSINES	COSH= -.4277996E+00	COSV= .8749415E+00	COSL= .2268588E+00
PRINCIPAL ANGLES	FROM +H=115.33 DEG	FROM +V= 28.96 DEG	FROM +L= 76.89 DEG

DESATURATION COEF. = .1725636E+02 (IPMAX+IPMID)/2 = .1558167E+12 LB/IN2, .3363149E+08 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE C 9

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MCDONNELL DOUGLAS

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 28 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE SOFT =1	33701.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
15	LOGISTIC =1	30001.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16	HAB/CONT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19	CREW SUPT MO	29101.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	ORB ADAPTER	1201.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR BOOM	18300.00	900.00	0.00	0.00	.1256400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
30	CRANE	3501.00	1560.00	-130.00	0.00	-0.	-0.	-0.
31	DRD ADPT =2	1201.00	1820.00	0.00	0.00	-0.	-0.	-0.
32	HAB MODULE	31001.00	1500.00	0.00	0.00	.2897900E+09	.1182400E+10	.1182400E+10
51	SHUTTLE -Z	200001.00	-159.00	493.00	.40	.3007900E+11	.3922700E+10	.2881800E+11
CONF. 226	TOTAL	387300.00	223.18	253.41	29.44	.7469992E+11	.1326956E+12	.1614339E+12
						SL-FT2	SL-FT2	SL-FT2
						.1612324E+08	.2864103E+08	.3484391E+08
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		175646.26	5.67	6.44	.75	.2186023E+08	.3883213E+08	.4724213E+08

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 226

TABLE 28 (2/2)

WEIGHT	387300.00 LBMASS		175646.26 KGMS
H-ARM	223.18 INCHES		5.67 METERS
V-ARM	253.41 INCHES		6.44 METERS
L-ARM	29.44 INCHES		.75 METERS
ROLL MOI	.7469992E+11 LB/IN2	.1612324E+08 SL-FT2	.2186123E+08 KG-M2
YAW MOI	.1326995E+12 LB/IN2	.2864103E+08 SL-FT2	.3883213E+08 KG-M2
PITCH MOI	.1614339E+12 LB/IN2	.3484391E+08 SL-FT2	.4724213E+08 KG-M2
ROLL POI	-.2850427E+10 LB/IN2	-.6152364E+06 SL-FT2	-.8341509E+06 KG-M2
YAW POI	.1097828E+09 LB/IN2	.2369553E+05 SL-FT2	.3212691E+05 KG-M2
PITCH POI	-.3834539E+11 LB/IN2	-.8276472E+07 SL-FT2	-.1122142E+08 KG-M2
PRINCIPAL MOI 1	.1620606E+12 LB/IN2	.3497916E+08 SL-FT2	.4742551E+08 KG-M2
DIRECTION COSINES	COSH= .9412266E-01	COSV= .2172172E+00	COSL= .9715748E+00
PRINCIPAL ANGLES	FROM +H= 84.60 DEG	FROM +V= 77.45 DEG	FROM +L= 13.69 DEG
PRINCIPAL MOI 2	.5560467E+11 LB/IN2	.1200172E+08 SL-FT2	.1627219E+08 KG-M2
DIRECTION COSINES	COSH= .8950391E+00	COSV= -.4456997E+00	COSL= .1293310E-01
PRINCIPAL ANGLES	FROM +H= 26.49 DEG	FROM +V=116.47 DEG	FROM +L= 89.26 DEG
PRINCIPAL MOI 3	.1511642E+12 LB/IN2	.3262729E+08 SL-FT2	.4423680E+08 KG-M2
DIRECTION COSINES	COSH= .4358399E+00	COSV= .8684287E+00	COSL= -.2363792E+00
PRINCIPAL ANGLES	FROM +H= 64.15 DEG	FROM +V= 29.72 DEG	FROM +L=103.67 DEG

DESATURATION COEF. = .1853973E+02 (IPMAX+IPMID)/2 = .1566124E+12 LB/IN2. .3380323E+08 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE C 10

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 29 (1/2)

ITEM	DESCRIPTION	WEIGHT	X ARM	Y ARM	Z ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE SOFT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
15	LOGISTIC =1	30000.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16	HAB/COLT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19	CREW SUPT MO	29100.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR BOOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
30	CRANE	3500.00	1680.00	-130.00	0.00	-0.	-0.	-0.
31	ORB ADPT =2	1200.00	1920.00	0.00	0.00	-0.	-0.	-0.
32	FAB MODULE	31000.00	1500.00	0.00	0.00	.2897900E+09	.1182400E+10	.1182400E+10
52	SHUTTLE +Y	200000.00	-159.00	.40	493.00	.3007900E+11	.2881800E+11	.3922700E+10
CONF. 227	TOTAL	387300.00	223.18	-.97	283.82	.6870732E+11	.1753377E+12	.1127992E+12
						SL-FT2	SL-FT2	SL-FT2
						.1482979E+08	.3784490E+08	.2434659E+08
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		175646.26	5.67	-.02	7.21	.2010656E+08	.5131094E+08	.3300964E+08

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

MCDONNELL DOUGLAS

TABLE 29 (2/2)

HPS3 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 227

WEIGHT	387300.00 LBMASS			175646.26 KGMS	
H-ARM	223.18 INCHES			5.67 METERS	
V-ARM	-.97 INCHES			-.02 METERS	
L-ARM	283.82 INCHES			7.21 METERS	
ROLL MOI	.6870732E+11 LB/IN2	.1462979E+08 SL-FT2		.2010656E+08 KG-M2	
YAW MOI	.1753377E+12 LB/IN2	.3764490E+08 SL-FT2		.5131094E+08 KG-M2	
PITCH MOI	.1127992E+12 LB/IN2	.2434659E+08 SL-FT2		.3300964E+08 KG-M2	
ROLL POI	.1458730E+09 LB/IN2	.3148524E+05 SL-FT2		.4268837E+05 KG-M2	
YAW POI	-.3754216E+11 LB/IN2	-.8103107E+07 SL-FT2		-.1098637E+08 KG-M2	
PITCH POI	-.6934291E+09 LB/IN2	-.1496698E+06 SL-FT2		-.2029255E+06 KG-M2	
PRINCIPAL MOI 1	.1753424E+12 LB/IN2	.3784591E+08 SL-FT2		.5131231E+08 KG-M2	
DIRECTION COSINES	COSH= .7203930E-02	COSV= .9999721E+00		COSL= .1991942E-02	
PRINCIPAL ANGLES	FROM +H= 89.59 DEG	FROM +V= .43 DEG		FROM +L= 89.89 DEG	
PRINCIPAL MOI 2	.4721308E+11 LB/IN2	.1019047E+08 SL-FT2		.1361647E+08 KG-M2	
DIRECTION COSINES	COSH= .8678599E+00	COSV= -.5262579E-02		COSL= -.4967829E+00	
PRINCIPAL ANGLES	FROM +H= 29.79 DEG	FROM +V= 90.30 DEG		FROM +L=119.79 DEG	
PRINCIPAL MOI 3	.1342888E+12 LB/IN2	.2898490E+08 SL-FT2		.3929835E+08 KG-M2	
DIRECTION COSINES	COSH= .4967595E+00	COSV= -.5307514E-02		COSL= .8678725E+00	
PRINCIPAL ANGLES	FROM +H= 60.21 DEG	FROM +V= 90.30 DEG		FROM +L= 29.79 DEG	
DESATURATION COEF. =	.5242047E+01	(IPMAX+IPMID)/2 =	.1548156E+12 LB/IN2.	.3341540E+08 SL-FT2	

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE C 11

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 30 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE SOFT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
15	LOGISTIC =1	30000.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16	HAB/COMT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19	CREW SUPT MO	29100.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	FWD BOOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
30	CRANE	3500.00	1680.00	-130.00	0.00	-0.	-0.	-0.
31	ORB ADPT =2	1200.00	1820.00	0.00	0.00	-0.	-0.	-0.
32	FAB MODULE	31000.00	1500.00	0.00	0.00	.2897900E+09	.1182400E+10	.1182400E+10
42	COMP FAB UNT	10273.00	1560.00	0.00	-392.00	.2200000E+09	.2200000E+09	.5600000E+08
44	UNIVERSAL TR	12963.00	1580.00	392.00	0.00	.2200000E+09	.5600000E+08	.2200000E+09
68	STRONG BACK	4000.00	2100.00	30.00	0.00	.4000000E+08	.2000000E+09	.2000000E+09
CONF. 126	TOTAL	214536.00	772.24	22.12	34.01	.2491856E+11	.1004323E+12	.8076061E+11
						SL-FT2	SL-FT2	SL-FT2
						.5378423E+07	.2167731E+08	.1743138E+08
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		97295.24	19.61	.56	.86	.7292183E+07	.2939057E+08	.2363384E+08

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 126

TABLE 30 (2/2)

WEIGHT	214536.00 LBMASS		97295.24 KGMS	
H=ARM	772.24 INCHES		19.61 METERS	
V=ARM	22.12 INCHES		.56 METERS	
L=ARM	34.01 INCHES		.86 METERS	
ROLL MOI	.2491656E+11 LB/IN2	.5378473E+07 SL-FT2	.7292183E+07 KG-M2	
YAW MOI	.1004323E+12 LB/IN2	.2167731E+08 SL-FT2	.2939057E+08 KG-M2	
PITCH MOI	.8076061E+11 LB/IN2	.1743138E+08 SL-FT2	.2363384E+08 KG-M2	
ROLL POI	-.1614419E+09 LB/IN2	-.3484564E+05 SL-FT2	-.4724447E+05 KG-M2	
YAW POI	-.9732783E+10 LB/IN2	-.2100724E+07 SL-FT2	-.2848208E+07 KG-M2	
PITCH POI	.4359097E+10 LB/IN2	.9408678E+06 SL-FT2	.1275649E+07 KG-M2	
PRINCIPAL MOI 1	.1006915E+12 LB/IN2	.2173327E+08 SL-FT2	.2946644E+08 KG-M2	
DIRECTION COSINES	COSH= -.6014541E-01	COSV= .9979626E+00	COSL= -.2128698E-01	
PRINCIPAL ANGLES	FROM +H= 93.45 DEG	FROM +V= 3.66 DEG	FROM +L= 91.22 DEG	
PRINCIPAL MOI 2	.2302917E+11 LB/IN2	.4970617E+07 SL-FT2	.6739271E+07 KG-M2	
DIRECTION COSINES	COSH= .9845236E+00	COSV= .5579175E-01	COSL= -.1661341E+00	
PRINCIPAL ANGLES	FROM +H= 10.09 DEG	FROM +V= 86.80 DEG	FROM +L= 99.56 DEG	
PRINCIPAL MOI 3	.8239073E+11 LB/IN2	.1778322E+08 SL-FT2	.2411088E+08 KG-M2	
DIRECTION COSINES	COSH= .1645350E+00	COSV= .3094974E-01	COSL= .9858734E+00	
PRINCIPAL ANGLES	FROM +H= 80.53 DEG	FROM +V= 88.23 DEG	FROM +L= 9.64 DEG	
DESATURATION COEF. = .7487316E+01	(IPMAX+IPMID)/2 =	.9154113E+11 LB/IN2.	.1975824E+08 SL-FT2	

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 31 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE 50FT =1	33700.00	360.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
15	LOGISTIC =1	30000.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16	HAB/CONT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19	CREW SUPT MO	29100.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	CRF ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	FWF ROOM	18500.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	500.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
30	CRANE	3500.00	1680.00	-130.00	0.00	-0.	-0.	-0.
31	CRF ADPT =2	1200.00	1920.00	0.00	0.00	-0.	-0.	-0.
32	FAB MODULE	31000.00	1500.00	0.00	0.00	.2897900E+09	.1182400E+10	.1182400E+10
42	COMP FAB UNT	10273.00	1680.00	0.00	-392.00	.2200000E+09	.2200000E+09	.5600000E+08
44	UNIVERSAL TR	12963.00	1680.00	392.00	0.00	.2200000E+09	.5600000E+08	.2200000E+09
50	SHUTTLE +Z	200000.00	-159.00	-493.00	-.40	.3007900E+11	.3922700E+10	.2881300E+11
68	STRONG BACK	4000.00	2100.00	30.00	0.00	.4000000E+08	.2000000E+09	.2000000E+09
CONF. 228	TOTAL	414536.00	322.95	-226.41	17.41	.8258594E+11	.1942385E+12	.2260054E+12
						SL-FT2	SL-FT2	SL-FT2
						.1782535E+08	.4192446E+08	.4895370E+08
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		187998.19	8.20	-5.75	.44	.2416800E+08	.5684210E+08	.6637249E+08

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

MCDONNELL DOUGLAS

HP53 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 228

TABLE 31 (2/2)

WEIGHT	414536.00 LBMASS		187998.19 KGMS
H-ARM	322.95 INCHES		8.20 METERS
V-ARM	-226.41 INCHES		-5.75 METERS
L-ARM	17.41 INCHES		.44 METERS
ROLL MOI	.8258594E+11 LB/IN2	.1782535E+08 SL-FT2	.2416800E+08 KG-M2
YAW MOI	.1942305E+12 LB/IN2	.4192446E+08 SL-FT2	.5684210E+08 KG-M2
PITCH MOI	.2268054E+12 LB/IN2	.4895370E+08 SL-FT2	.6637249E+08 KG-M2
ROLL POI	.1673410E+10 LB/IN2	.3611889E+06 SL-FT2	.4897077E+06 KG-M2
YAW POI	-.6415799E+10 LB/IN2	-.1384778E+07 SL-FT2	-.1877512E+07 KG-M2
PITCH POI	.5401147E+11 LB/IN2	.1165784E+08 SL-FT2	.1580595E+08 KG-M2

PRINCIPAL MOI 1	.2282611E+12 LB/IN2	.4926789E+08 SL-FT2	.6679848E+08 KG-M2
DIRECTION COSINES	COSH= .1438957E+00	COSV= -.2751908E+00	COSL= .9505599E+00
PRINCIPAL ANGLES	FROM +H= 81.73 DEG	FROM +V=105.97 DEG	FROM +L= 18.09 DEG
PRINCIPAL MOI 2	.6056426E+11 LB/IN2	.1317219E+08 SL-FT2	.1772357E+08 KG-M2
DIRECTION COSINES	COSH= .9268394E+00	COSV= .3740914E+00	COSL= -.3200393E-01
PRINCIPAL ANGLES	FROM +H= 22.05 DEG	FROM +V= 68.03 DEG	FROM +L= 91.83 DEG
PRINCIPAL MOI 3	.2148045E+12 LB/IN2	.4636343E+08 SL-FT2	.6286055E+08 KG-M2
DIRECTION COSINES	COSH= -.3467891E+00	COSV= .8856216E+00	COSL= .3088878E+00
PRINCIPAL ANGLES	FROM +H=110.29 DEG	FROM +V= 27.67 DEG	FROM +L= 72.01 DEG

DESATURATION COEF. = .2392420E+02 (IPMAX+IPMID)/2 = .2215328E+12 LB/IN2, .4781566E+08 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE C 13

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 32 (1/2)

ITEM DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12 CORE SCFT =1	33700.00	310.00	0.00	0.00	.9522000E+08	.4076100E+09	.4078100E+09
15 LOGISTIC =1	38000.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16 [illegible]	[illegible]	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19 [illegible]	[illegible]	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23 [illegible]	-1200.00	[illegible]	0.00	0.00	-0.	-0.	-0.
26 [illegible]	[illegible]	900.00	0.00	0.00	[illegible]	[illegible]	[illegible]
28 ARRAY-DEPLOY	[illegible]	[illegible]	0.00	0.00	.6797300E+10	[illegible]	.3460900E+09
30 [illegible]	[illegible]	1640.00	-150.00	0.00	-0.	-0.	-0.
31 CREW ADPT =2	[illegible]	1520.00	0.00	0.00	-0.	-0.	-0.
32 [illegible] MODULE	[illegible]	1500.00	0.00	0.00	[illegible]	[illegible]	.1181400E+10
42 [illegible]	[illegible]	1540.00	0.00	-392.00	[illegible]	[illegible]	.5600000E+08
44 UNIVERSAL TR	12966.00	1560.00	392.00	0.00	.2200000E+09	.5600000E+08	.2200000E+09
63 RADIOMET 30M	38601.00	2200.00	-340.10	0.00	.5471500E+10	.3513400E+10	.5727100E+10
68 STRONG BACK	4001.00	2100.00	30.00	0.00	.4000000E+08	.2000000E+09	.2000000E+09
CONF. 129 TOTAL	253136.00	989.95	-17.86	28.83	.3267737E+11	.1766612E+12	.1554250E+12
					SL-FT2	SL-FT2	SL-FT2
					.7053086E+07	.3683555E+08	.3354693E+08
	KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
	114800.91	25.14	-.45	.73	.9562728E+07	.4994244E+08	.4548367E+08

SCR L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 129

TABLE 32 (2/2)

WEIGHT	253136.00 LBMASS		114800.91 KGMS
H-ARM	969.95 INCHES		25.14 METERS
V-ARM	-17.86 INCHES		-.45 METERS
L-ARM	28.83 INCHES		.73 METERS
ROLL MOI	.3267737E+11 LB/IN2	.7053086E+07 SL-FT2	.9562728E+07 KG-M2
YAW MOI	.1706613E+12 LB/IN2	.3683555E+08 SL-FT2	.4994244E+08 KG-M2
PITCH MOI	.1554250E+12 LB/IN2	.3354693E+08 SL-FT2	.4548367E+08 KG-M2
ROLL POI	.1303344E+09 LB/IN2	.2813138E+05 SL-FT2	.3814114E+05 KG-M2
YAW POI	-.1132145E+11 LB/IN2	-.2443623E+07 SL-FT2	-.3313117E+07 KG-M2
PITCH POI	-.7888846E+10 LB/IN2	-.1702729E+07 SL-FT2	-.2308597E+07 KG-M2

PRINCIPAL MOI 1	.1711287E+12 LB/IN2	.3693644E+08 SL-FT2	.5007922E+08 KG-M2
DIRECTION COSINES	COSH= .5968465E-01	COSV= .9976123E+00	COSL= .3474923E-01
PRINCIPAL ANGLES	FROM +H= 86.58 DEG	FROM +V= 3.96 DEG	FROM +L= 88.01 DEG
PRINCIPAL MOI 2	.3119600E+11 LB/IN2	.6733779E+07 SL-FT2	.9129805E+07 KG-M2
DIRECTION COSINES	COSH= .9942864E+00	COSV= -.5632730E-01	COSL= -.9067361E-01
PRINCIPAL ANGLES	FROM +H= 6.13 DEG	FROM +V= 93.23 DEG	FROM +L= 95.20 DEG
PRINCIPAL MOI 3	.1564369E+12 LB/IN2	.3376535E+08 SL-FT2	.4577980E+08 KG-M2
DIRECTION COSINES	COSH= .8849977E-01	COSV= -.3996251E-01	COSL= .9952742E+00
PRINCIPAL ANGLES	FROM +H= 84.92 DEG	FROM +V= 92.29 DEG	FROM +L= 5.57 DEG

DESATURATION COEF. = .1804678E+02 (IPMAX+IPMID)/2 = .1637828E+12 LB/IN2. .3535089E+08 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION TABLE 33 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE 50FT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
15	LOGISTIC =1	30001.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16	HAB/CONT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19	CREW SUPT MO	29100.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	FAB BOOM	10300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
30	CRANE	3500.00	1550.00	-130.00	0.00	-0.	-0.	-0.
31	ORB ADPT =2	1200.00	1620.00	0.00	0.00	-0.	-0.	-0.
32	FAB MODULE	31000.00	1500.00	0.00	0.00	.2897900E+09	.1182400E+10	.1182400E+10
42	COMP FAB UNT	10273.00	1580.00	0.00	-392.00	.2240000E+09	.2200000E+09	.5600000E+08
44	UNIVERSAL TR	12963.00	1680.00	392.00	0.00	.2200000E+09	.5600000E+08	.2200000E+09
50	SHUTTLE +Z	200000.00	-159.00	-493.00	-.40	.3007900E+11	.3922700E+10	.2881800E+11
63	RADIOMET 30M	38600.00	2200.00	-240.10	0.10	.5471500E+10	.3503400E+10	.5727100E+10
68	STRONG BACK	4000.00	2100.0	30.00	0.00	.4000000E+08	.2000000E+09	.2000000E+09
CONF. 229	TOTAL	453136.00	482.84	-227.57	15.93	.8807476E+11	.3221682E+12	.3569547E+12
						SL-FT2	SL-FT2	SL-FT2
						.1901006E+08	.6953682E+08	.7704513E+08
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		205563.85	12.26	-5.78	.40	.2577426E+08	.9427953E+08	.1044595E+09

SCR L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

M253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 229

TABLE 33 (2/2)

WEIGHT	453136.00 LBMASS		205503.85 KGMS
H-ARM	482.84 INCHES		12.26 METERS
V-ARM	-227.57 INCHES		-5.78 METERS
L-ARM	15.93 INCHES		.40 METERS
ROLL MOI	.8807476E+11 LB/IN2	.1901006E+08 SL-FT2	.2577426E+08 KG-M2
YAW MOI	.3221682E+12 LB/IN2	.6953682E+06 SL-FT2	.9427953E+08 KG-M2
PITCH MOI	.3569547E+12 LB/IN2	.7704513E+08 SL-FT2	.1044595E+09 KG-M2
ROLL POI	.1681626E+10 LB/IN2	.3630059E+06 SL-FT2	.4921713E+06 KG-M2
YAW POI	-.7569720E+10 LB/IN2	-.1633849E+07 SL-FT2	-.2215208E+07 KG-M2
PITCH POI	.5310381E+11 LB/IN2	.1146193E+08 SL-FT2	.1554033E+08 KG-M2
PRINCIPAL MOI 1	.3575712E+12 LB/IN2	.7717819E+08 SL-FT2	.1046399E+09 KG-M2
DIRECTION COSINES	COSH= .5266398E-01	COSV= -.1260551E+00	COSL= .9906244E+00
PRINCIPAL ANGLES	FROM +H= 86.95 DEG	FROM +V= 97.24 DEG	FROM +L= 7.85 DEG
PRINCIPAL MOI 2	.7641467E+11 LB/IN2	.1649335E+06 SL-FT2	.2236204E+08 KG-M2
DIRECTION COSINES	COSH= .9771586E+00	COSV= .2109801E+00	COSL= -.2510178E-01
PRINCIPAL ANGLES	FROM +H= 12.27 DEG	FROM +V= 77.82 DEG	FROM +L= 91.44 DEG
PRINCIPAL MOI 3	.3332119E+12 LB/IN2	.7192048E+08 SL-FT2	.9751135E+08 KG-M2
DIRECTION COSINES	COSH= -.2053379E+00	COSV= .9693284E+00	COSL= .1342880E+00
PRINCIPAL ANGLES	FROM +H=101.89 DEG	FROM +V= 14.23 DEG	FROM +L= 82.29 DEG

DESATURATION COEF. = .2208415E+02   (IPMAX+IPMID)/2 = .3453915E+12 LB/IN2,   .7454933E+08 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH OA KASULKA 2FEB77

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 34 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE SECT #1	7 00.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
15	LOGISTIC #1	30000.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16	HAB/CONT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19	CREW SUPT MO	29100.00	490.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR BOOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10500.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3456900E+09
30	CRANE	3500.00	1680.00	-130.00	0.00	-0.	-0.	-0.
31	ORB ADPT #2	1200.00	1820.00	0.00	0.00	-0.	-0.	-0.
32	FAB MODULE	31500.00	1500.00	0.00	0.00	.2857900E+09	.1182400E+10	.1182400E+10
42	COMP FAB UNT	10273.00	1680.00	0.00	-392.00	.2200000E+09	.2200000E+09	.5600000E+08
44	UNIVERSAL TR	12963.00	1680.00	392.00	0.00	.2200000E+09	.5600000E+08	.2200000E+09
64	MBL ANT	65700.00	1934.00	0.00	0.00	.8873500E+10	.1073500E+11	.1112200E+11
68	STRONG BACK	4000.00	2100.00	30.00	0.00	.4000000E+08	.2000000E+09	.2000000E+09
CONF, 130	TOTAL	280236.00	1044.61	16.94	26.04	.3367460E+11	.1791110E+12	.1597928E+12
						SL-FT2	SL-FT2	SL-FT2
						.7311553E+07	.3865933E+08	.3448968E+08
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		127091.16	26.53	.43	.66	.9913163E+07	.5241516E+08	.4670186E+08

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB72

H253 PROGRAM*VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 130

TABLE 34 (2/2)

WEIGHT	280236.00 LBMASS		127091.16 KGMS
H*ARM	1044.61 INCHES		26.53 METERS
V*ARM	16.94 INCHES		.43 METERS
L*ARM	26.04 INCHES		.66 METERS
ROLL MOI	.3387486E*11 LB/IN2	.7311553E+07 SL*FT2	.9913163E+07 KG*M2
YAW MOI	.1791110E*12 LB/IN2	.3865933E+08 SL*FT2	.5241516E+08 KG*M2
PITCH MOI	.1597929E*12 LB/IN2	.3448968E+08 SL*FT2	.4676166E+08 KG*M2
ROLL POI	*.1235926E*09 LB/IN2	*.2667624E+05 SL*FT2	*.3616823E+05 KG*M2
YAW POI	*.1172526E*11 LB/IN2	*.2529702E+07 SL*FT2	*.3429825E+07 KG*M2
PITCH POI	.3066294E*10 LB/IN2	.6618291E+06 SL*FT2	.8973223E+06 KG*M2
PRINCIPAL MOI 1	.1791765E*12 LB/IN2	.3867347E+08 SL*FT2	.5243434E+08 KG*M2
DIRECTION COSINES	COSH* *.2163871E*01	COSV* .9997433E+00	COSL* *.6709248E*02
PRINCIPAL ANGLES	FROM +H* 91.24 DEG	FROM +V* 1.30 DEG	FROM +L* 90.38 DEG
PRINCIPAL MOI 2	.3272909E*11 LB/IN2	.7064248E+07 SL*FT2	.9577862E+07 KG*M2
DIRECTION COSINES	COSH* .9955529E+00	COSV* .2093161E*01	COSL* *.9184944E*01
PRINCIPAL ANGLES	FROM +H* 5.41 DEG	FROM +V* 88.80 DEG	FROM +L* 95.27 DEG
PRINCIPAL MOI 3	.1608730E*12 LB/IN2	.3472284E+08 SL*FT2	.4707798E+08 KG*M2
DIRECTION COSINES	COSH* .9168543E*01	COSV* .8666915E*02	COSL* .9957503E+00
PRINCIPAL ANGLES	FROM +H* 84.74 DEG	FROM +V* 89.50 DEG	FROM +L* 5.28 DEG

DESATURATION COEF. = .1500210E*02 (IPMAX+IPMID)/2 = .1700248E*12 LB/IN2, .3669816E+08 SL*FT2

SCB L PERMAN*MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE C 1

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 35 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE SUPT #1	33700.00	300.00	0.00	0.00	.5522000E+08	.4078100E+09	.4078100E+09
15	LOGISTIC #1	30000.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16	HAB/CONT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19	CREW SUPT MO	29100.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR BOOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6757300E+10	.7144000E+10	.3466900E+09
30	CRANE	3900.00	1680.00	-130.00	0.00	-0.	-0.	-0.
31	ORB ADPT #2	1200.00	1820.00	0.00	0.00	-0.	-0.	-0.
32	FAB MODULE	31500.00	1500.00	0.00	0.00	.2857900E+09	.1182400E+10	.1182400E+10
42	COMP FAB UNT	10273.00	1680.00	0.00	-392.00	.2200000E+09	.2200000E+09	.5600000E+08
44	UNIVERSAL TR	12963.00	1680.00	392.00	0.00	.2200000E+09	.5600000E+08	.2200000E+09
50	SHUTTLE #2	250000.00	-159.00	-493.00	-.40	.3007900E+11	.3922700E+10	.2881800E+11
64	MRL ANT	65700.00	1934.00	0.00	0.00	.8873500E+10	.1073500E+11	.1112200E+11
68	STRONG BACK	4000.00	2100.00	30.00	0.00	.4000000E+08	.2000000E+09	.2000000E+09
CONF, 23C	TOTAL	480236.00	543.35	-195.43	15.03	.9438369E+11	.3521859E+12	.3880296E+12
						SL-FT2	SL-FT2	SL-FT2
						.2037177E+08	.7601582E+08	.8375233E+08
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		217794.10	13.80	-4.96	.38	.2762050E+08	.1030639E+09	.1135532E+09

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 230

TABLE 35 (2/2)

WEIGH.	480236.00 LBMASS		217794.10 KGMS
H-ARM	543.35 INCHES		13.80 METERS
V-ARM	-195.43 INCHES		-4.96 METERS
L-ARM	15.03 INCHES		.38 METERS
ROLL MOI	.9438369E+11 LB/IN2	.2037177E+08 SL-FT2	.2762050E+08 KG-M2
YAW MOI	.3521859E+12 LB/IN2	.7601582E+08 SL-FT2	.1030639E+09 KG-M2
PITCH MOI	.3880294E+12 LB/IN2	.8375233E+08 SL-FT2	.1135532E+09 KG-M2
ROLL PCI	.1449970E+10 LB/IN2	.3129400E+06 SL-FT2	.4242909E+06 KG-M2
YAW POI	-.8006416E+10 LB/IN2	-.1728105E+07 SL-FT2	-.2343003E+07 KG-M2
PITCH PCI	.7469929E+11 LB/IN2	.1612265E+08 SL-FT2	.2185945E+08 KG-M2

PRINCIPAL MOI 1	.3889278E+12 LB/IN2	.8394619E+08 SL-FT2	.1138161E+09 KG-M2
DIRECTION COSINES	COSH= .7513215E-01	COSV= -.1913637E+00	COSL= .9786394E+00
PRINCIPAL ANGLES	FROM +H= 85.69 DEG	FROM +V=101.03 DEG	FROM +L= 11.86 DEG
PRINCIPAL MOI 2	.7413194E+11 LB/IN2	.1600064E+08 SL-FT2	.2169402E+08 KG-M2
DIRECTION COSINES	COSH= .9655236E+00	COSV= .2592589E+00	COSL= -.2342959E-01
PRINCIPAL ANGLES	FROM +H= 15.09 DEG	FROM +V= 74.97 DEG	FROM +L= 91.34 DEG
PRINCIPAL MOI 3	.3715394E+12 LB/IN2	.8019309E+08 SL-FT2	.1087275E+09 KG-M2
DIRECTION COSINES	COSH= -.2492374E+00	COSV= .9466598E+00	COSL= .2042448E+00
PRINCIPAL ANGLES	FROM +H=104.43 DEG	FROM +V= 18.80 DEG	FROM +L= 78.21 DEG

DESATURATION COEF. = .3520767E+02 (IPMAX+IPMID)/2 = .3802336E+12 LB/IN2, .8206964E+08 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE C 2

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 36 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	CORE 50FT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
15	LOGISTIC =1	30000.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16	HAB/CONT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19	CREW SUPT MO	29100.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR BOOM	18300.00	900.00	0.00	0.00	.1256400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
30	CRANE	3500.00	1680.00	-130.00	0.00	-0.	-0.	-0.
31	CRD ADPT =2	1200.00	1820.00	0.00	0.00	-0.	-0.	-0.
32	FAB MODULE	31000.00	1500.00	0.00	0.00	.2697900E+09	.1182400E+10	.1182400E+10
42	COMP FAB UNT	10273.00	1680.00	0.00	-392.00	.2200000E+09	.2200000E+09	.5600000E+08
44	UNIVERSAL TR	12963.00	1680.00	392.00	0.00	.2200000E+09	.5600000E+08	.2200000E+09
602	TA-2	49227.00	7785.00	-105.00	0.00	.5252000E+10	.4891200E+12	.4848700E+12
632	TA-2 F-A JIG	29018.00	1790.30	-95.23	0.00	.2909800E+10	.2974100E+10	.4720800E+09
CONF. 131	TOTAL	288781.00	2051.57	-11.45	25.27	.3397362E+11	.2563692E+13	.2538074E+13
						SL-FT2	SL-FT2	SL-FT2
						.7332669E+07	.5533475E+09	.5478181E+09
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		130966.44	52.11	-.29	.64	.9942064E+07	.7502406E+09	.7427438E+09

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77 PAGE A 1

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 131

TABLE 36 (2/2)

WEIGHT	288781.00 LBMASS		130966.44 KGMS
H-ARM	2051.57 INCHES		52.11 METERS
V-ARM	-11.45 INCHES		-.29 METERS
L-ARM	25.27 INCHES		.64 METERS
ROLL MOI	.3397362E+11 LB/IN2	.7332869E+07 SL-FT2	.9942064E+07 KG-M2
YAW MOI	.2563692E+13 LB/IN2	.5533475E+09 SL-FT2	.7502406E+09 KG-M2
PITCH MOI	.2538074E+13 LB/IN2	.5478181E+09 SL-FT2	.7427438E+09 KG-M2
ROLL POI	.8352976E+08 LB/IN2	.1802907E+05 SL-FT2	.2444421E+05 KG-M2
YAW POI	-.1906809E+11 LB/IN2	-.4115658E+07 SL-FT2	-.5580099E+07 KG-M2
PITCH POI	-.3063222E+11 LB/IN2	-.6611660E+07 SL-FT2	-.8964233E+07 KG-M2

PRINCIPAL MOI 1	.2564064E+13 LB/IN2	.5534278E+09 SL-FT2	.7503494E+09 KG-M2
DIRECTION COSINES	COSH= .1214903E-01	COSV= .9999100E+00	COSL= .5699809E-02
PRINCIPAL ANGLES	FROM +H= 89.30 DEG	FROM +V= .77 DEG	FROM +L= 89.67 DEG
PRINCIPAL MOI 2	.3345759E+11 LB/IN2	.7221489E+07 SL-FT2	.9791052E+07 KG-M2
DIRECTION COSINES	COSH= .9998977E+00	COSV= -.1210549E-01	COSL= -.7612802E-02
PRINCIPAL ANGLES	FROM +H= .82 DEG	FROM +V= 90.69 DEG	FROM +L= 90.44 DEG
PRINCIPAL MOI 3	.2538219E+13 LB/IN2	.5478493E+09 SL-FT2	.7427860E+09 KG-M2
DIRECTION COSINES	COSH= .7543118E-02	COSV= -.5791715E-02	COSL= .9999548E+00
PRINCIPAL ANGLES	FROM +H= 89.57 DEG	FROM +V= 90.33 DEG	FROM +L= .54 DEG

DESATURATION COEF. = .1948263E+03 (IPMAX+IPMID)/2 = .2551141E+13 LB/IN2, .5506385E+09 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH OA KASULKA 2FEB77 PAGE C 1

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION

TABLE 37 (1/2)

ITEM	DESCRIPTION	WEIGHT	H ARM	V ARM	L ARM	ROLL MOI	YAW MOI	PITCH MOI
12	COPE 50FT =1	33700.00	300.00	0.00	0.00	.9522000E+08	.4078100E+09	.4078100E+09
15	LOGISTIC =1	30000.00	120.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
16	HAB/CONT MOD	29300.00	360.00	0.00	-380.00	.3995400E+09	.3995400E+09	.1566500E+09
19	CREW SUPT MO	29100.00	480.00	0.00	380.00	.3995400E+09	.3995400E+09	.1566500E+09
23	ORB ADAPTER	1200.00	-20.00	0.00	0.00	-0.	-0.	-0.
26	PWR BOOM	18300.00	900.00	0.00	0.00	.1258400E+08	.1514100E+09	.1514100E+09
28	ARRAY-DEPLOY	10000.00	900.00	0.00	0.00	.6797300E+10	.7144000E+10	.3466900E+09
30	CRANE	3500.00	1660.00	-130.00	0.00	-0.	-0.	-0.
31	ORB ADPT =2	1200.00	1820.00	0.00	0.00	-0.	-0.	-0.
32	FAB MODULE	31000.00	1500.00	0.00	0.00	.2897900E+09	.1182400E+10	.1182400E+10
42	COMP FAB UNT	10273.00	1660.00	0.00	-392.00	.2200000E+09	.2200000E+09	.5600000E+08
44	UNIVERSAL TR	12963.00	1680.00	392.00	0.00	.2200000E+09	.5600000E+08	.2200000E+09
50	SHUTTLE +Z	200000.00	-159.00	-493.00	-.40	.3007900E+11	.3922700E+10	.2881800E+11
602	TA-2	49227.00	7785.00	-105.00	0.00	.5252000E+10	.4891200E+12	.4848700E+12
632	TA-2 F-A JIG	29018.00	1790.30	-95.23	0.00	.2909000E+10	.2974100E+10	.4726800E+09
CONF. 231	TOTAL	488781.00	1147.05	-208.49	14.77	.9153184E+11	.3145116E+13	.3171717E+13
						SL-FT2	SL-FT2	SL-FT2
						.1975624E+08	.6788421E+09	.6845836E+09
		KGMS	METERS	METERS	METERS	KG-M2	KG-M2	KG-M2
		221669.39	29.14	-5.30	.38	.2678594E+08	.9203890E+09	.9281734E+09

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

PAGE A 2

H253 PROGRAM--VEHICLE MASS PROPERTIES DETERMINATION
PRINCIPAL AXES DATA
CONFIGURATION 231

TABLE 37 (2/2)

WEIGHT	488781.00 LBMASS		221669.39 KGMS
H-ARM	1147.05 INCHES		29.14 METERS
V-ARM	-208.49 INCHES		-5.30 METERS
L-ARM	14.77 INCHES		.38 METERS
ROLL MOI	.9155184E+11 LB/IN2	.1975624E+08 SL-FT2	.2678594E+08 KG-M2
YAW MOI	.3145116E+13 LB/IN2	.6768421E+09 SL-FT2	.9203690E+09 KG-M2
PITCH MOI	.3171717E+13 LB/IN2	.6845636E+09 SL-FT2	.9281734E+09 KG-M2
ROLL POI	.1544106E+10 LB/IN2	.3332799E+06 SL-FT2	.4518681E+06 KG-M2
YAW POI	-.1236330E+11 LB/IN2	-.2668495E+07 SL-FT2	-.3618004E+07 KG-M2
PITCH POI	.9515407E+11 LB/IN2	.2053806E+08 SL-FT2	.2784595E+08 KG-M2

PRINCIPAL MOI 1	.3171922E+13 LB/IN2	.6846279E+09 SL-FT2	.9282334E+09 KG-M2
DIRECTION COSINES	COSH= .6465155E-02	COSV= -.8043618E-01	COSL= .9967387E+00
PRINCIPAL ANGLES	FROM +H= 89.63 DEG	FROM +V= 94.61 DEG	FROM +L= 4.63 DEG
PRINCIPAL MOI 2	.8852043E+11 LB/IN2	.1910626E+08 SL-FT2	.2590468E+08 KG-M2
DIRECTION COSINES	COSH= .9995079E+00	COSV= .3111340E-01	COSL= -.3992341E-02
PRINCIPAL ANGLES	FROM +H= 1.80 DEG	FROM +V= 88.22 DEG	FROM +L= 90.23 DEG
PRINCIPAL MOI 3	.3147923E+13 LB/IN2	.6794479E+09 SL-FT2	.9212102E+09 KG-M2
DIRECTION COSINES	COSH= -.3069080E-01	COSV= .9962740E+00	COSL= .8059837E-01
PRINCIPAL ANGLES	FROM +H= 91.76 DEG	FROM +V= 4.95 DEG	FROM +L= 85.36 DEG

DESATURATION COEF. = .2559558E+03 (IPMAX+IPMID)/2 = .3159922E+13 LB/IN2, .6820379E+09 SL-FT2

SCB L PERMAN-MANNED DIRECT GROWTH DA KASULKA 2FEB77

MCDONNELL DOUGLAS

Table 38

DAKTUG COMPUTER PROGRAM OPTIONS

```
 DAKTUG      07:44    FEB 17,'77

 WHAT IS DATA FILE NAME?
?DAKDATA
 DØ YØU WANT TØ CHANGE INPUT DATA?
?YES
?TDUR=720.
?*
 DØ YØU WISH LØAD CARRYING TANK(5) ØR SHELL(6)?
?6
 WHAT IS THE SIZING MISSIØN;DEPLØYMENT(1),
 RETRIEVAL(2),ØR RØUNDTRIP(3)?
?3
 WHAT TYPE ØF SHELL STRUCTURE: ISØGRID-AL(5),HØNEYCØMB-AL(6),ISØGRID-GR.

 EP.(7),HØNEYCØMB-GR.EP.(8)?
?7
 WHICH MATERIAL:2219=1,7475=2,2024=3?
?1
 DØ YØU WISH TAPERED(17) ØR CØNSTANT(18) T DØMES?
?17
 WHAT MATERIAL IS TANK SUPPØRTS;FIBERGLASS-ISØGRID(1),
 TITANIUM-TUBULAR(2),ØR FIBERGLASS-TUBULAR(3)?
?3
 WHAT MATERIAL IS THRUST STRUCTURE;ALUMINUM(4),
 FIBERGLASS EPØXY(5),ØR TITANIUM(6)?
?5
 IS SHELL STRUCTURE ØPEN?
?NØ
 IS DØCKING SPINUP REQUIRED?
?NØ
 IS METEØRØID PRØTECTIØN ØVER LH2 SW SAME AS SHELL?
?YES
 IS VARIABLE DIAMETER DØCKING REQUIRED?
?NØ
 WHICH INSULATIØN ØPTIØN:CØATING(1) ØR MLI(2)?
?2
 WHICH ENGINE IS DESIRED:CATI/RL-10(1),
 CATII/RL-10(2),CATIIA/RL-10(3),CATIV/RL-10(4),
 CATIIB/RL-10(5),AERØSPIKE(6),ADVANCE SPACE(7),
 CATIV W ZNPSH(8),AERØSPIKE MR=5(9),
 CATIIA W/Ø ZNPSH(10)?
?3
 HØW MANY ENGINES?
?2
 DØES ENGINE  ØPERATE INITIALLY AT ZNPSH?
?YES
```

Table 38 (cont)

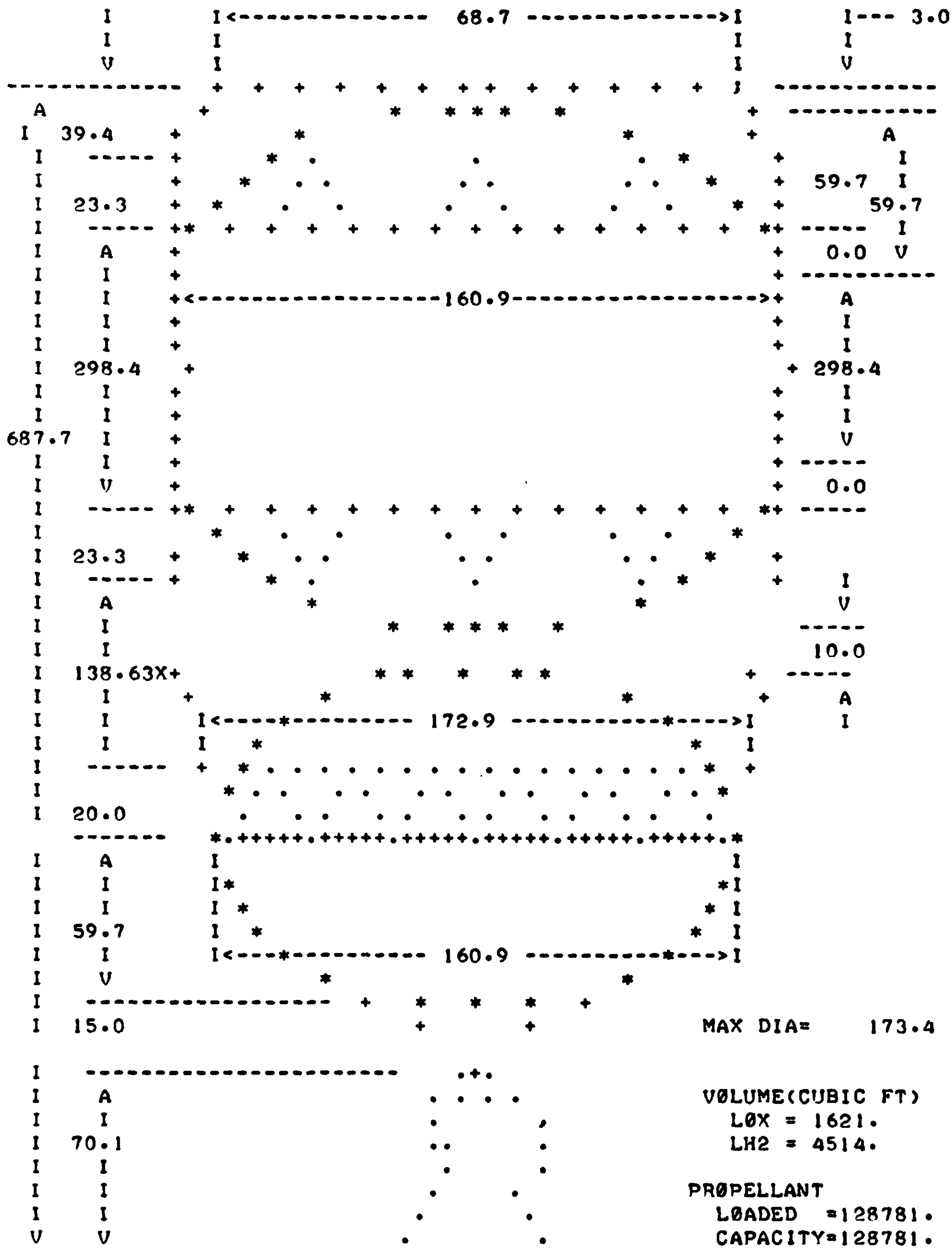
DAKTUG COMPUTER PROGRAM OPTIONS

```
 WHICH PRESSURIZATION OPTION+1,2,3,4,5,6,7,8,9,10,11?
?1
 ARE PROPULSION LINES DIRECT DEVELOPMENT(1),OR PHASED LINES(2)?
?1
 HOW MANY LINES;SINGLE=1,DUAL=2,ETC.
?2
 ARE VACUUMM JACKETED LH2 LINES DESIRED?
?YES
 VENT SYSTEM:NEW=1,DEVELOPED=2?
?1
 TVC TRIDENT(1),OR APPOLLO(2)?
?1
 WHAT IS MAX TOTAL IMPLUSE FOR APS SIZING(AIMPLU)?
?216000.
 DO YOU WISH NEW(1) OR DEVELOPED(2) APS HARDWARE?
?1
 WHICH APS PROP; PRESSURIZED N2H4(4), BLOWDOWN
 N2H4(5),MMH:N204(6),OR CRYO H2/02(7)?
?6
 WHICH DATA MANAGEMENT OPTION IS DESIRED:1A=1,1B=2,
 1C=3,2A=4,2B=5,2C=6,3A=7,3B=8,3C=9,3D=10,3E=11,3F=12?
?5
 WHICH GNC OPTION:1,2,3,4,5.6,OR 7?
?2
 WHICH COMMUNICATIONS OPTION:1,2,3,OR 4?
?1
 WHICH RENDEZVOUS & DOCKING OPTION:
 NONE=1,5A=2,5B=3,5C=4,5D=5,& 5E=6?
?4
 HOW MUCH AREA FOR THERMAL PANELS(SQ-FT)?
?50.
 WHAT IS LEVEL OF CHECKOUT,LIMITED=1,AUTONOMOUS=2?
?2
 DO YOU WANT BATTERIES-OPTION 1 OR 2,OR
 FUEL CELLS-OPTION 3,4,OR 5?
?4
 IF FUEL CELLS,DO YOU WANT PW(125 LB)=1,OR
 GE(75 LB)=2,OR PW(34 LB)=3?
?2
 DO YOU WISH PROPELLANT PRINTOUT?
?YES
 DO YOU WISH AREA &VOLUME PRINYOUTS?
?YES
 DO YOU WANT CONFIGURATION DRAWING?
?YES
 IS TANKAGE DEFINED?
?NO
 IS PERFORMANCE DATA REQUIRED?
?NO
```

Table 39

OTV--PRELIMINARY CONFIGURATION PRINTOUT

LØAD CARRYING TANK CØNFIGURATIØN



MAX DIA= 173.4

VØLUME(CUBIC FT)
LØX = 1621.
LH2 = 4514.

PRØPELLANT
LØADED =128781.
CAPACITY=128781.

Table 40

OTV-1 AREA AND VOLUME PRINTOUT

SURFACE AREA - SQ FT

FWD SKIRT CØVER	8.
FWD SKIRT	96.
TANK SUPPØRT	0.
SIDEWALL	1305.
TANK SUPPØRT	0.
INTERTANK	530.
TANK SUPPØRT	81.
AFT LØX DØME	246.
TØTAL WETTED AREA	2266.
LH2 DØMES	491.
LH2 SIDEWALL	1048.
LH2 TANK AREA	1539.
LØX DØMES	491.
LØX SIDEWALL	184.
LØX TANK AREA	676.

ENVELØPE VØLUME - CUBIC FT

LH2 DØMES	1003.
LH2 CLY TANK	3512.
LH2 TANK VØLUME	4514.
TANK SUPT & INTERTANK VØL	721.
LØX TANK VØLUME	1621.
TØTAL ENVELØPE VØLUME	6856.

Table 41

OTV-1 DETAIL WEIGHT PRINTOUT

STRUCTURE	3665.
FUEL TANK AND SUPPØRT	966.
LH2 TANK SUPPØRTS	38.
DØMES	231.
SIDEWALL	658.
Y-RINGS	18.
BAFFLES	0.
SUPPØRTS	0.
ACCESS CØVERS	18.
SUMPS	3.
LØX TANK AND SUPPØRT	452.
LØX TANK SUPPØRTS	53.
DØMES	234.
SIDEWALL	122.
Y-RINGS	18.
BAFFLES	0.
SUPPØRTS	0.
ACCESS CØVERS	16.
SUMPS	8.
BØDY STRUCTURE	1642.
SHELL	1459.
FØRWARD SKIRT	0.
CØNIC SHELL	282.
SIDEWALL SHELL	627.
INTERTANK SHELL	511.
AFT SKIRT	0.
PAINT	24.
ACCESS PRØVISIØNS	15.
SUPPØRTS	183.
THRUST STRUCTURE	335.
SHELL	330.
SUPPØRTS	5.
METEØRØID SHIELD	44.
PAYLØAD INTERFACE	226.
DØCKING - PAYLØAD	175.
PAYLØAD UMBILICAL PRØVISIØNS	51.

Table 41 (cont)

OTV-1 DETAIL WEIGHT PRINTOUT

THERMAL CØNTRØL		1053.
FUEL TANK INSULATIØN	(NØ. LAYERS=144.)	637.
LH2 DØMES		200.
LH2 SIDEWALL		427.
LH2 TANK SUPPØRTS		9.
LØX TANK INSULATIØN	(NØ. LAYERS=149.)	320.
LØX DØMES		284.
LØX TANK SUPPØRTS		36.
INSULATIØN PURGE SYSTEM		97.
PURGE LINER		78.
PLUMBING		19.
AVIØNICS		1524.
DATA MANAGEMENT		249.
CØMPUTER		32.
MIU		206.
DCU		8.
RDP		0.
MISCELLANEØUS		3.
GNC		80.
IMU		20.
STAR SENSØR		20.
SUN SENSØR		0.
HØRIZØN SENSØR		0.
HØRIZØN SENSØR ELECTRØNICS		0.
RENDEZVØUS & DØCKING ELECTRØNICS		40.
MISCELLANEØUS		0.
CØMMUNICATIØN		152.
ANTENNAS		10.
MULTIPLEXERS		4.
PØWER AMPLIFIERS		16.
TRANSPØNDER		38.
CØMMAND DECØDER		5.
PRØCESSØR		0.
CØMMAND ENCØDER		3.
CØMSEC EQUIPMENT		12.
TAPE RECØRDER		40.
TRANSMITTER		0.
FREQUENCY SYNTHESIZER		0.
CMD UNITS		0.
MISCELLANEØUS		24.

Table 41 (cont)

OTV-1 DETAIL WEIGHT PRINTOUT

INSTRUMENTAIØN		275.	
SENSØRS			31.
SIGNAL CØNDITIØNING			44.
CIRCUITRY			200.
PCM TELEMETRY			0.
ELECTRICAL PØWER SØURCE		495.	
BATTERIES-PRIMARY			0.
BATTERY-TVC			40.
BATTERIES-BACKUP			0.
FUEL CELLS			150.
REACTANT TANKAGE			266.
PLUMBING			25.
WATER ACCUMULATØR			13.
PØWER DISTRIBUTIØN AND CØNTRØL		112.	
PØWER DISTRIBUTIØN UNITS			21.
BUS BAR			20.
CIRCUITRY-PWR			71.
EQUIPTMENT THERMAL CØNTRØL		162.	
THERMAL PANELS			89.
HEAT PIPES			26.
SPLICE MECHANISM			30.
HØUSING-CØVERS			15.
MISC			2.
PRØPULSIØN	2295.		
MAIN ENGINE (GFE)		952.	
MAIN ENGINE SUPPØRT		1143.	
GIMBAL ACTUATØRS			38.
PURGE PRØVISIØNS			44.
UMBILICALS			56.
ABØRT PRØVISIØNS			36.
FEED			436.
VENT			258.
FILL AND DRAIN			106.
PNEUMATICS			93.
PU SYSTEM			76.
PRESSURIZATIØN			0.
BØTTLES			0.
CØNTRØLS & LINES			0.
HELIUM HEATER			0.
ACPS ENGINE		61.	
ACPS ENGINE SUPPØRT		139.	

Table 41 (cont)

OTV-1 DETAIL WEIGHT PRINTOUT

DRY WEIGHT SUBTØTAL	8537.		
CØNTINGENC(10%)	854.		
TØTAL DRY WEIGHT	9391.		
FPR LØX			327.
FPR LH2			55.
FLIGHT PERFØRMANCE RESERVES		382.	
PU LØX			275.
PU LH2			45.
PRØPELLANT UTILIZATIØN		320.	
LØX PRESSURIZATIØN			0.
LH2 PRESSURIZATIØN			0.
RESIDUAL GØ2			308.
RESIDUAL GH2			418.
HE PRES-LØX TANK			0.
HE PRES-LH2 TANK			0.
HE TRAPPED			0.
PRESSURIZATIØN GASES		726.	
LØX PRØPELLANT			228.
LH2 PRØPELLANT			39.
APS			2.
FUEL CELL RECANT			26.
TRAPPED PRØPELLANT		295.	
RESIDUALS		1723.	
BURNØUT WEIGHT	11114.		

Table 42

OTV-1 DETAIL INFLIGHT LOSSES PRINTOUT

EXCESS LØX TANKAGE	(0.)
EXCESS LH2 TANKAGE	(0.)
EXCESS-PØTENTIAL USEABLE	(0.)
USEABLE LØX	108096.
USEABLE LH2	18016.
USEABLE MAIN PRØPELLANT	126112.
APS EXCESS	(600.)
APS MMH/N2Ø4	192.
APS LØX	0.
APS LH2	0.
APS N2H4	0.
APS PRØPELLANT ISP= 272.	192.
LØX	0.
LH2	0.
CHILLDØWN	0.
LØX	548.
LH2	353.
VENT PRØPELLANT	901.
LØX	203.
LH2	137.
IDLE PRØPELLANT	340.
LØX	501.
LH2	62.
FUEL CELL REACTANTS	563.
LØX	0.
LH2	0.
GAS GENERATØR PRØPELLANT	0.
INFLIGHT LØSSES	128108.
TØTAL LØX IN TANK	109757.
TØTAL LH2 IN TANK	19024.
TØTAL PRØPELLANT IN TANKS	128781.
PRØPELLANT BULK DENSITY	22.553
FINIAL MIXTURE RATIØ	5.769

Table 43 (Page 1 of 2)

OTV MASS SUMMARY

Description	Stage Mass (Kg) Booster		Upper	
Structure	1,662		1,587	
Fuel Tank and Supports		438		438
Lox Tank and Supports		205		205
Body Structure		744		744
Thrust Structure		152		77
Meteoroid Shield		20		20
Payload Interface		103		103
Thermal Control	478		478	
Avionics	692		677	
Data Management		113		113
GNC		36		36
Communication		69		69
Instrumentation		125		122
Electrical Power Source		225		215
Power Distribution and Control		51		50
Equipment Thermal Control		73		72
Propulsion	1,041		655	
Engines		432		216
Support		518		348
ALPS		91		91
Dry Weight	(3,873)		(3,397)	
Contingency	387		340	
Total Dry Weight	(4,260)		(3,737)	
Residuals	781		725	
FPR		173		173
PU		145		145
Pressurization (GO_2/GH_2)		329		329
Trapped		134		78

Table 43 (Page 2 of 2)
OTV MASS SUMMARY

Description	Stage Mass (Kg) Booster		Upper	
Burnout	(5,041)		(4,462)	
Inflight Losses	58,383		58,383	
APS Maximum Capacity		359		359
Vent Propellant		409		409
Idle Propellant		154		154
Fuel Cell Reactant		255		255
Usable		57,206		57,206
Ignition	(63,424)		(62,845)	